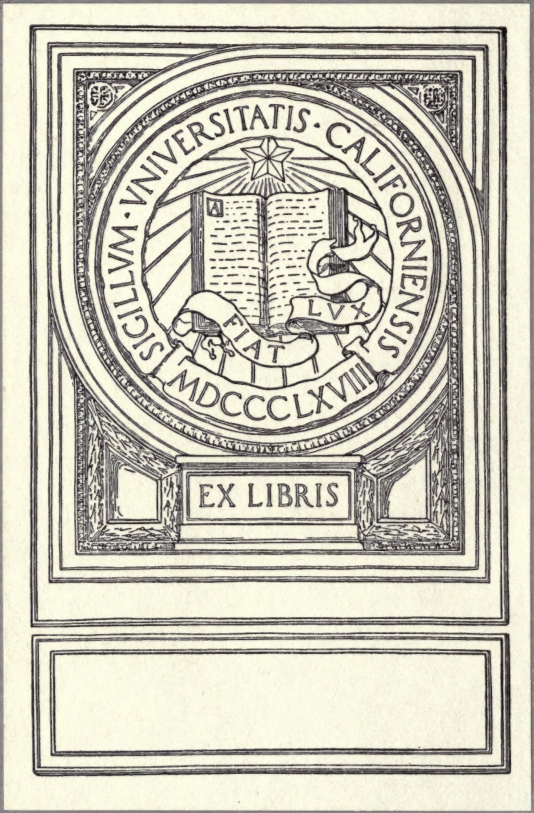
BERKELEY
LIBRARY
UNIVERSITY OF
CALIFORNIA

EARTH
SCIENCES
LIBRARY



# MINERALOGY

## AN INTRODUCTION TO THE STUDY OF MINERALS AND CRYSTALS

McGraw-Hill Book Co. Inc.

PUBLISHERS OF BOOKS FOR

Coal Age ▿ Electric Railway Journal
Electrical World ▿ Engineering News-Record
American Machinist ▿ Ingeniería Internacional
Engineering & Mining Journal ▿ Power
Chemical & Metallurgical Engineering
Electrical Merchandising

# MINERALOGY

## AN INTRODUCTION TO THE STUDY OF MINERALS AND CRYSTALS

BY

EDWARD HENRY KRAUS, PH.D., SC.D.

PROFESSOR OF CRYSTALLOGRAPHY AND MINERALOGY AND DIRECTOR OF THE MINERALOGICAL LABORATORY, UNIVERSITY OT MICHIGAN

AND

WALTER FRED HUNT, PH.D.

ASSOCIATE PROFESSOR OF MINERALOGY AND PETROGRAPHY, UNIVERSITY OF MICHIGAN

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK: 239 WEST 39TH STREET

LONDON: 6 & 8 BOUVERIE ST., E. C. 4

1920

QE363
K73
EARTH
SCIENCE
LIBRARY

Copyright, 1920, by the
McGraw-Hill Book Company, Inc.

OF THE
UNIVERSITY
OF
CALIFORNIA

THE MAPLE PRESS YORK PA

# PREFACE

This text is the result of long experience in teaching large classes of beginning students, and the subject is accordingly presented in a direct and simple manner. The essentials of the various phases of the science have been treated so that a single book may serve the needs of the average student. The conventional line drawings of crystals, which students commonly have difficulty in properly visualizing, have been superseded to a very large extent by excellent photographs of crystal models, natural crystals, and minerals, such as are actually handled in the laboratory. These are all original photographs of material contained in the various collections of the University of Michigan.

Furthermore, an attempt has been made to vitalize the subject as much as possible, and accordingly there are chapters on the importance of mineralogy in modern civilization, on gems and precious stones, and on the production and uses of the important economic minerals. Numerous photographs and short sketches of distinguished mineralogists have also been introduced in the hope that they will add a human touch.

The chapters on crystallography are based very largely upon the senior author's Essentials of Crystallography, while much of the material in the descriptions of the 150 minerals given in this text has been taken from his Descriptive Mineralogy. The determinative tables are an abridgment of the authors' Mineral Tables.

We are greatly indebted to Mr. George R. Swain, technical expert in photography in the University of Michigan, whose varied experience and unusual skill made the excellent photographs of models and minerals possible; also to Dr. George F. Kunz for valuable assistance in securing a considerable number of very desirable photographs.

Edward H. Kraus.
Walter F. Hunt.

Mineralogical Laboratory,
University of Michigan,
*August*, 1920.

427653

# CONTENTS


| | | Page |
|---|---|---|
| Introduction | | vii |
| Chapter | | |
| I. | Crystallography | 1 |
| II. | Cubic System | 14 |
| III. | Hexagonal System | 30 |
| IV. | Tetragonal System | 55 |
| V. | Orthorhombic System | 65 |
| VI. | Monoclinic System | 72 |
| VII. | Triclinic System | 78 |
| VIII. | Compound Crystals | 82 |
| IX. | Physical Properties | 88 |
| X. | The Polarizing Microscope | 99 |
| XI. | Chemical Properties | 125 |
| XII. | Formation and Occurrence of Minerals | 131 |
| XIII. | Qualitative Blowpipe Methods | 145 |
| XIV. | Descriptive Mineralogy | 186 |
| | 1. Elements | 187 |
| | 2. Sulphides, Arsenides, and Sulpho-minerals | 202 |
| | 3. Oxides and Hydroxides | 219 |
| | 4. Haloids | 236 |
| | 5. Nitrates, Carbonates, and Manganites | 240 |
| | 6. Sulphates, Chromates, Molybdates, Tungstates, and Uranates | 254 |
| | 7. Aluminates, Ferrites, and Borates | 267 |
| | 8. Phosphates, Columbates, and Vanadates | 272 |
| | 9. Silicates and Titanites | 277 |
| XV. | Gems and Precious Stones | 329 |
| XVI. | Classification of Minerals According to Elements | 339 |
| Glossary | | 366 |
| Tabular Classification of the Thirty-two Classes of Symmetry | | 372 |
| Tables for the Determination of Minerals | | 379 |
| Index | | 549 |

# INTRODUCTION

**Mineralogy and Civilization.**—The older classifications of natural history commonly referred substances occurring in nature to the animal, vegetable, or mineral kingdoms. The first of these kingdoms considered the animal life on land, in the sea, and in the air, and from a study of these animal forms there has been developed zoology with its host of allied sciences, such as anatomy, surgery, animal breeding, and so forth. The second kingdom included the plants and trees, and the study of these has given us the science of botany and such closely related subjects as forestry and agriculture. The mineral kingdom, in the opinion of the ancients, included the whole inanimate world; in short, minerals, rocks, soil, and the "waters of the earth." Inasmuch as bright colors, regularity of form, transparency, and other prominent properties have always attracted attention, there is little wonder that minerals with their great diversity of colors and form should have been among the first objects studied by primitive man.

Although mineralogy as a science is comparatively young, minerals and crystals were nevertheless used very early in the development of civilization. In fact, the earliest stage in the development of civilization is commonly referred to as the stone age. In this age rocks or stones were hewn into numerous shapes and used for utensils of various kinds. They were also made into crude weapons. At first the stones were for the most part rough, but subsequently methods were devised so that they could be rendered smooth and polished to some extent. Therefore this period is frequently divided into the rough and smooth stone ages, the paleolithic and neolithic ages, respectively.

As his knowledge of rocks and minerals increased and he was able to recover metals from the rocks, man emerged successively into the copper, bronze, iron, and coal ages. The present day is commonly called the motor age, a motor being an assemblage of metals. Indeed, as our civilization becomes more advanced and complex, the demand for metals of all sorts and hence for minerals ever increases.

**Sources of Raw Materials.**—The principal sources of raw materials are; the mines and quarries, the farms, the forests, the sea, and the atmosphere. Of these, the farms, forests, and the mines and quarries are the greatest contributors.

**Divisions of Human Activity.**—Upon the exploitation of these natural resources rest the greatest and most important divisions of human activity, namely, agriculture, mining, and commerce and industry. As is well known, agriculture furnishes us with many of the products so

necessary to our sustenance; that is, with the cereals and other crops. Indirectly, it gives us much of our meat products, wearing apparel, and the like. However, in order to carry on agriculture with marked success, a knowledge of the composition and nature of soils is absolutely essential. Soils, however, consist of minerals and mineral products to a very large extent. Indeed, all balanced soils suited to general cropping contain a preponderance of mineral matter.

It is obvious that in mining a most comprehensive knowledge of mineralogy is necessary. In many localities, mining is by far the chief occupation. Indeed, as Del Mar says, "Desire for the precious metals, rather than geographical researches or military conquest, is the principal motive which has led to the dominion of the earth by civilized races. Gold has invariably invited commerce, invasion has followed commerce, and permanent occupation has completed the process." Several comparatively recent instances will be cited. The stimulus given to world-wide migration and trade by the discovery of gold in California in 1849 is well known. For gold, Englishmen began to populate antipodal Australia in 1850. The discovery of diamonds near Kimberley in 1867 and of gold in the Rand district in 1885 led to the subsequent settlement of large sections of South Africa. Alaska came into prominence only after the discovery of gold and other valuable minerals late in the nineties.

Mining is often the fore-runner of agriculture. It is also to a large extent the basis of commerce and industry. In fact, commerce and industry may be said to rest in general upon agriculture and mining. The exploitation of valuable mineral deposits leads invariably to the development of lines of transportation and communication. Thus, the principal commerce of the Great Lakes consists of carrying enormous quantities of iron ore from the Lake Superior region to various points on the lower lakes and of transporting coal from these ports on the return trip. Likewise, many of the industries in the vicinity of the Great Lakes are directly dependent upon mining in that they utilize the products of the mines and quarries. Furthermore, conservative estimates show that nearly two-thirds of the total traffic of our railroads consists of the carrying of minerals and mineral products.

**The Nation and its Mineral Resources.**—The importance of a nation's resources has been emphasized by the World War. Indeed, the mineral resources of a nation are now recognized as one of its foundations of power and are considered among its most valuable assets. The great contributions of the United States in the winning of the war consisted largely in supplying enormous quantities of materials that were, directly or indirectly, the products of the mines or of the soil. This was to be expected of a country which under normal conditions produces 60 per cent. of the world's copper, 40 per cent. of the iron, 32 per cent. of its lead and zinc, 66 per cent. of the petroleum, 40 per cent. of its coal, 72 per cent. of

the corn, 20 per cent. of the wheat, and 60 per cent of its cotton. Director G. O. Smith of the United States Geological Survey says: "Independence through possession of the material resources essential to modern life is itself a promise of a nation's integrity, and the nation that makes the whole world its debtor through shipments of the mineral fuels and the metals and the mineral fertilizers occupies a strategic position in the construction of international policy."

**Relation of Mineralogy to Other Sciences.**—Mineralogy, then, must be considered as a subject which is fundamental to a large extent. It is a subject of vital importance to many types of students, among whom mention may be made of students of geology, chemistry, pharmacy, physics, forestry, soils, and engineering, not to include those looking forward to mineralogy as a profession.

The geologist whose task it is to observe and interpret the processes which are, and have been, at work upon the earth, should be well grounded in mineralogy, for the earth consists largely of rocks which in turn are made up of minerals. The chemist and the pharmacist are dealing to a large extent with raw materials which consist of minerals. Many of the important chemical processes are dependent wholly or in part upon the use of minerals. This is especially true of inorganic chemistry. Thus, the well-known Solvay process for the manufacture of the alkalies uses as raw materials—limestone, halite or common salt, and coal—products of the mines or quarries. Moreover, it has recently been shown that the synthetic compounds of the organic chemist and the alkaloids of the pharmacist can in very many instances be rapidly determined by the use of refined optical methods which have been devised by the mineralogist.

Many of the important laws in physics, especially those relating to the properties of light, have been studied principally on crystallized minerals. The Nobel prizes in physics for 1914 and 1915 were awarded to Laue and the Braggs (father and son) for epoch making investigations upon the structure of crystallized minerals by means of the $x$-ray.

In this country, the forester and the student of soils very frequently are at work in new and undeveloped sections. In their field surveys, they are able to recognize at a glance the character of the soil and of the rock exposures. They should further be able to pass fairly accurate judgment upon the possible value of any minerals or ore deposits they find. In order to do this, some knowledge of mineralogy is required.

In railroad, highway, and waterway construction, the engineer is constantly encountering problems which involve a knowledge of mineralogy. As in the case of the forester and the student of soils, he is frequently working in undeveloped sections of the country. Some of our most valuable ore deposits have been discovered as the direct result of railroad building. The great mineral deposits at Sudbury, Ontario,

which now furnish such enormous quantities of nickel, and the valuable silver mines at Cobalt, Ontario, to mention two recent examples only, were discovered in this way.

**History of Mineralogy.**—Mineralogy is a comparatively young science, having been developed more recently than astronomy, chemistry, mathematics, or physics. Although minerals and metals were frequently used by the ancients, the first extensive work on mineralogy did not appear until 1546, when Georg Agricola published his *De Natura Fossilium*. It is commonly conceded that Werner (1750–1817), for many years a professor in the famous school of mines at Freiburg, Saxony, was the first to place mineralogy upon a scientific basis. At first, mineralogy and geology were not differentiated, and only in comparatively recent times have they been recognized as distinct sciences.

FIG. 1.—Abraham G. Werner (1750–1817) pioneer mineralogist.

**Minerals and Rocks.**—The exterior of the earth is made up of solids, liquids, and occluded gases. The solids are commonly called rocks. It is with these that we are concerned. Let us consider the general characterstics of several of the most common rocks. In examining a granite, for example (Fig. 2), it is at once seen that it is heterogeneous in character; that is, it is made up of several constituents. In general, there is, first, a colorless, granular, and glassy material which is called quartz; second, a whitish substance with rather even surfaces, known as feldspar; and third, a dark

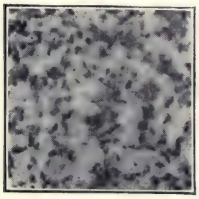


FIG. 2.—Granite.

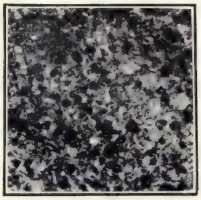


FIG. 3.—Syenite.

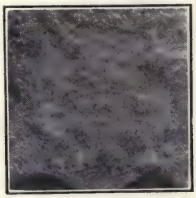


FIG. 4.—Sandstone.

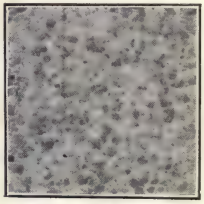


FIG. 5.—Marble.

colored and scaly material, which is commonly designated as mica. If these three crystalline constituents are analyzed, it will be noted that characteristic chemical compositions can be assigned to them. Thus, quartz, $SiO_2$, feldspar, $KAlSi_3O_8$, and mica, $KHMg_2Al_2Si_3O_{12}$. In examining another common rock such as syenite (Fig. 3) it will be found that it is quite frequently composed of two constituents—mica and feldspar. On the other hand, such rocks as sandstone (Fig. 4)

and marble (Fig. 5) consist of one component only, quartz and calcite, $CaCO_3$, respectively. When these substances are studied, it is frequently found that they occur in regular forms; that is, they are bounded by natural plane surfaces. These rock constituents are minerals.

**Definition of a Mineral.**—A mineral, then, may be defined as *a substance occurring in nature with a characteristic chemical composition, and usually possessing a definite crystalline structure, which is sometimes expressed in external geometrical forms or outlines.* Characteristic of a mineral is its occurrence in nature. The same chemical substance, for example $CaSO_4$, may be found in nature or may be prepared in the chemical laboratory. When found in nature it is designated as a mineral and has a special mineralogical name assigned to it, *anhydrite* (Fig. 6). When prepared in the laboratory it cannot be interpreted as a mineral and is usually referred to as calcium sulphate. Therefore, in order to be classified as a mineral, a substance must be the product of nature and not the result of processes carried on in the laboratory. Most minerals are inorganic in character and are either chemical elements or combinations of such elements; that is, chemical compounds. Some substances of an organic nature, such as coal, amber, petroleum, asphalt, and so forth, are frequently included. As indicated, a few minerals are very simple in composition, such as sulphur, silver, copper, and gold. These are elements.

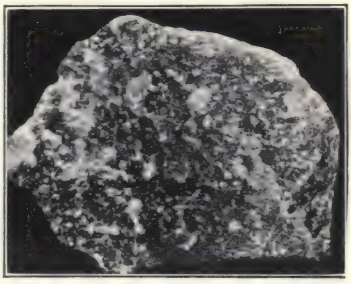


FIG. 6.—Anhydrite, oakwood salt shaft, Detroit, Michigan.

FIG. 7.—Calcite. Joplin, Missouri.

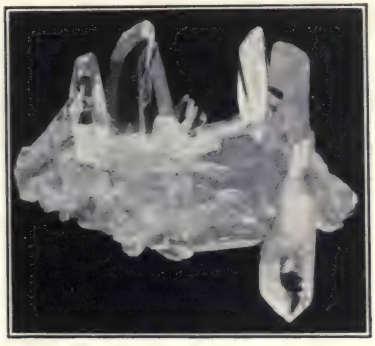


FIG. 8.—Quartz. Dauphiné, France.

**Crystals.**—When minerals occur with definite geometrical outlines they are called crystals (Figs. 7 and 8). Unlike minerals, crystals may

be the result of processes carried on either in nature or in the laboratory. They are solids bounded by natural plane surfaces called crystal faces. Many minerals are found as excellent crystals. Accurate and rapid determination of minerals can, in many cases, be most successfully made by recognizing the crystal form. Crystallography is the science which deals with the form and various properties of crystals. A knowledge of the essentials of geometrical crystallography is absolutely indispensible in the rapid determination of minerals.

**Divisions of Mineralogy.**—An elementary course in mineralogy may be conveniently divided into (1) crystallography, (2) physical mineralogy, (3) chemical mineralogy, (4) descriptive mineralogy, (5) determinative mineralogy.

*Crystallography.*—This portion of the text aims to make the student familiar with the common crystal forms exhibited by minerals, first by the study of crystal models and later by the recognition of the various forms exhibited by natural crystals.

*Physical Mineralogy.*—This includes the consideration of the various physical properties such as hardness, cleavage, color, luster, streak, specific gravity, as well as the various optical properties of crystallized minerals. The study of the properties last referred to involves the use of the mineralogical or polarizing microscope.

*Chemical Mineralogy.*—In this chapter the various chemical properties of minerals, and also their origin and formation, will be considered. The determination of their chemical constituents, especially by blowpipe methods, will be treated in detail.

*Descriptive Mineralogy.*—In this chapter one-hundred and fifty of the most common minerals will be described as to their crystallography, chemical and physical properties, occurrences and associates, and uses. There will also be included sections relating to the use of minerals as precious stones, statistics of mineral production and uses, and the classification of minerals according to their important chemical constituents.

*Determinative Mineralogy.*—For the purpose of acquiring facility in the rapid recognition of minerals by means of their physical properties, pages 380 to 547 contain determinative tables for the one hundred and fifty minerals described in this text.

# MINERALOGY

## AN INTRODUCTION TO THE STUDY OF MINERALS AND CRYSTALS

---

## CHAPTER I

### CRYSTALLOGRAPHY

**Subdivisions of Crystallography.**—This science treats of the various properties of crystals and crystallized bodies. It may be subdivided as follows:

1. Geometrical Crystallography.
2. Physical Crystallography.
3. Chemical Crystallography.

Geometrical crystallography, as the term implies, describes the various forms occurring upon crystals. The relationships existing between the crystal form and the physical and chemical properties of crystals are the subjects of discussion of the second and third subdivisions of this science, respectively. In order to be able to determine minerals rapidly at least, the essentials of geometrical crystallography must have been mastered.

**Constancy of Interfacial Angles.**—In general, crystals may result from solidification from a solution, state of fusion, or vapor. Let us suppose

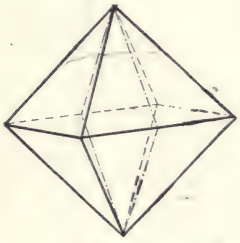


FIG. 9.

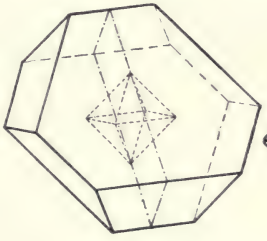


FIG. 10.

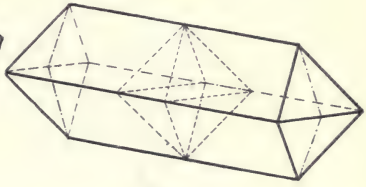


FIG. 11.

that some ammonium alum, $(NH_4)_2Al_2(SO_4)_4.24H_2O$, has been dissolved in water and the solution allowed to evaporate slowly. As the alum begins to crystallize, it will be noticed that the crystals are, for the most part, bounded by eight plane surfaces. If these surfaces are all of the same size, that is, equally developed, the crystals will possess an outline

as represented by Fig. 9. Such a form is termed an *octahedron*. The octahedron is bounded by eight equilateral triangles. The angles be-

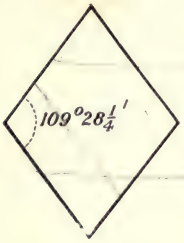



Fig. 12.

Fig. 13.

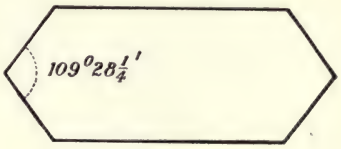



Fig. 14.

tween any two adjoining surfaces or *faces*, as they are often called, is the same, namely, 109° 28¼′. On most of the crystals, however, it will be seen that the various faces have been developed unequally, giving rise to the forms illustrated by Figs. 10 and 11. Similar cross-sections through these forms are shown in Figs. 12, 13, and 14, and it is readily seen that, although the size of the faces and, hence, the resulting shapes have been materially changed, the angle between the adjoining faces has remained the same, namely, 109° 28¼′. Such forms of the octahedron are said to be *misshapen* or *distorted*. *Distortion* is quite common on all crystals regardless of their chemical composition.

Fig. 15.—Nicolaus Steno (1638–1687). Discoverer of the law of the constancy of interfacial angles.

It was the Danish physician and natural scientist, Nicolaus Steno, (Fig. 15) who in 1669 first showed that the angles between similar faces on crystals of quartz remain constant regardless of their development. Figures 16

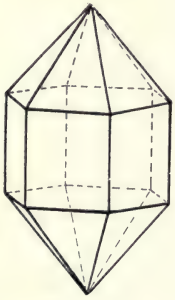


Fig. 16.

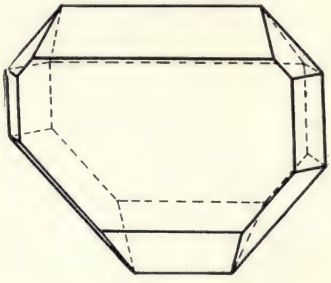


Fig. 17.

and 17 represent two crystals of quartz with similar cross-sections (Figs. 18 and 19). Further observations, however, showed that this

applies not only to quartz but to all crystallized substances and, hence, we may state the law as follows: *Measured at the same temperature, similar angles on crystals of the same substance remain constant regardless of the size or shape of the crystal.*

**Crystal Habit.**—The various shapes of crystals, resulting from the unequal development of their faces, are often called their *habits.* Figures 9, 10, and 11 show some of the habits assumed by alum

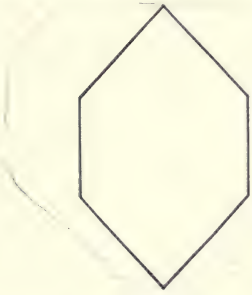


FIG. 18.

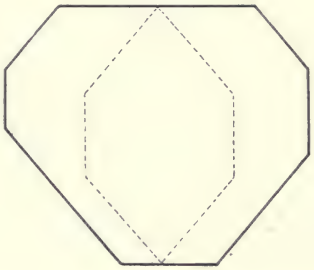


FIG. 19.

crystals. In Fig. 9, the eight faces are about equally developed and this may be termed the *octahedral* habit. The *tabular* habit, Fig. 10, is due to the predominance of two parallel faces. Figure 11 shows four parallel faces predominating, and the resulting form is the *prismatic* habit

**Crystallographic Axes.**—Inasmuch as the crystal form of any substance is dependent upon its physical and chemical properties, it necessarily follows that an almost infinite variety of forms is possible. In order, however, to study these forms and define the position of the

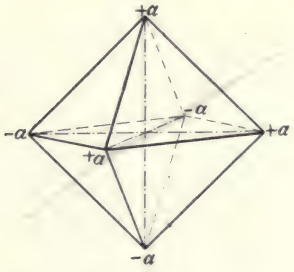



FIG. 20.

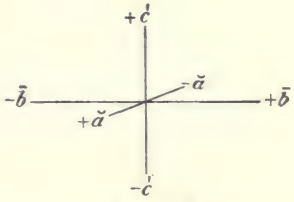



FIG. 21.

faces occurring on them advantageously, straight lines are assumed to pass through the ideal center of each crystal. These lines are the *crystallographic axes.* Their intersection forms the *axial cross.* Figure 20 shows the octahedron referred to its three crystal axes. In this case the axes are of equal length and termed *a* axes. The extremities of the axes are differentiated by the use of the plus and minus signs, as shown in Fig. 20.

If the axes are of unequal lengths, the one extending from front to rear is termed the *a* axis, the one from right to left the *b*, while the vertical axis is called the *c* axis. This is illustrated by Fig. 21. The axes are always referred to in the following order, viz.: *a*, *b*, *c*.

**Crystal Systems.**—Although a great variety of crystal forms is possible, it has been shown in many ways that all forms may be classified into six large groups, called *crystal systems*. In the grouping of crystal forms into systems, we are aided by the crystallographic axes. The systems may be differentiated by means of the axes as follows:

1. *Cubic System.*—Three axes, all of equal lengths, intersect at right angles. The axes are designated by the letters, *a*, *a*, *a*.

2. *Hexagonal System.*—Four axes, three of which are equal and in a horizontal plane intersecting at angles of 60°. These three axes are often termed the lateral axes, and are designated by *a*, *a*, *a*. Perpendicular to the plane of the lateral axes is the vertical axis, which may be longer or shorter than the *a* axes. This fourth axis is called the *principal* or *c* axis.

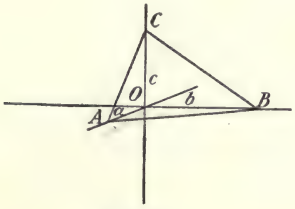



FIG. 22.

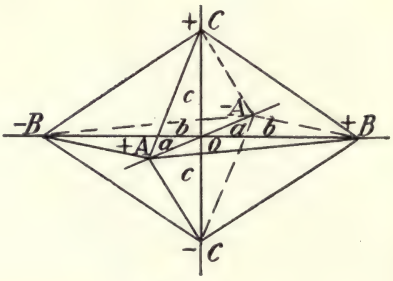



FIG. 23.

3. *Tetragonal System.*—Three axes, two of which are equal, horizontal, and perpendicular to each other. The vertical, *c*, axis is at right angles to and either longer or shorter than the horizontal or *lateral*, *a*, axes. The vertical axis is often called the *principal* axis.

4. *Orthorhombic System.*—Three axes of unequal lengths intersect at right angles. These axes are designated by $\breve{a}$, $\bar{b}$, $\dot{c}$, as shown in Fig. 21.

5. *Monoclinic System.*—Three axes, all unequal, two of which ($\acute{a}$, $\dot{c}$) intersect at an oblique angle, the third axis ($\bar{b}$) being perpendicular to these two.

6. *Triclinic System.*—Three axes ($\breve{a}$, $\bar{b}$, $\dot{c}$,) are all unequal and intersect at oblique angles.

**Parameters and Parametral Ratio.**—In order to determine the position of a face on a crystal, it must be referred to the crystallographic axes. Figure 22 shows an axial cross of the orthorhombic system. The axes, *a*, *b*, *c*, are, therefore, unequal and perpendicular to each other. The plane *ABC* cuts the three axes at the points *A*, *B*, and *C*, hence, at

the distance $OA = a$, $OB = b$, $OC = c$, from the center, $O$. These distances, $OA$, $OB$, and $OC$, are known as the *parameters* and the ratio, $OA : OB : OC$, as the *parametral ratio* of the plane $ABC$. This ratio may be abbreviated to $a : b : c$.

There are, however, seven other planes possible about this axial cross which possess parameters of the same lengths as those of the plane $ABC$, Fig. 23. The simplified ratios of these planes are:

$$\begin{aligned} a &: -b : c \\ a &: b : -c \\ a &: -b : -c \\ -a &: b : c \\ -a &: -b : c \\ -a &: b : -c \\ -a &: -b : -c \end{aligned}$$

These eight planes are all similarly located with respect to the crystallographic axes. They constitute a *crystal form*, and may be represented by the general ratio $(a : b : c)$. The number of faces in a crystal form depends, moreover, not only upon the intercepts or parameters but also upon the elements of symmetry possessed by the crystal, see page 10. Those forms, which enclose space, are called *closed* forms. Figure 23 is such a form. Those, however, which do not enclose space on all sides, as shown in Fig. 24, are termed *open* forms.

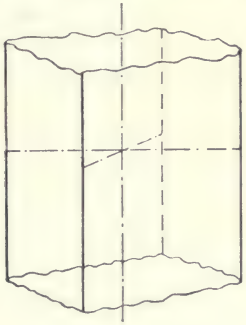


FIG. 24.

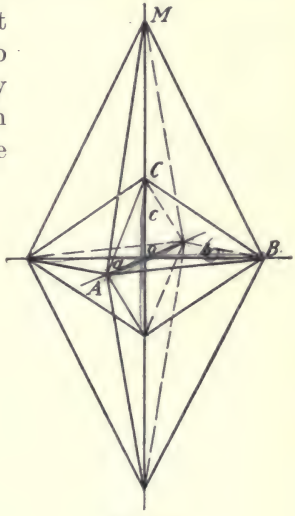



FIG. 25.

**Fundamental and Modified Forms.**—In Fig. 25, the enclosed form possesses the general ratio, $a : b : c$. The face $ABM$, however, has the parametral ratio, $oA : oB : oM$, where $oA = a$, $oB = b$, and $oM = 3oC = 3c$. Hence, this ratio may be written $a : b : 3c$. But, as in the previous case, this ratio represents a form consisting of eight faces as shown in the figure. That form, the parameters of which are selected as the unit

lengths of the crystallographic axes, is known as the *unit* or *fundamental* form In Fig. 25 the inner bipyramid, or double pyramid, is a so-called *unit*, whereas the outer is a *modified* form.

**Combinations.**—Several different forms may occur simultaneously upon a crystal, giving rise to a *combination*. Figures 26 and 27 show a combination of two bipyramids observed on sulphur; $p = a : b : c$

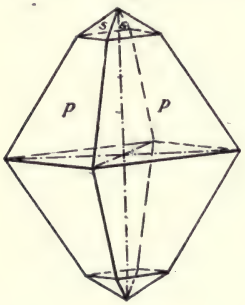



FIG. 26.

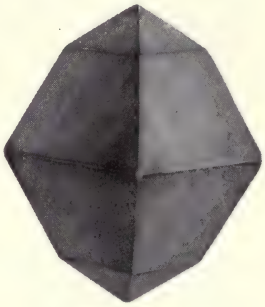


FIG. 27.

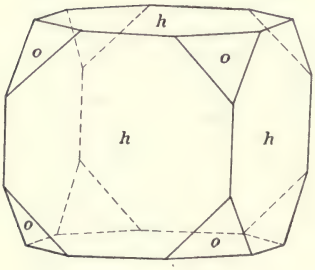



FIG. 28.

FIG. 29.

(unit) and $s = a : b : \frac{1}{3}c$ (modified). Figures 28 and 29 shows the two forms, $o = a : a : a$, and $h = a : \infty a : \infty a$, see page 16.

**Axial Ratio.**—If the intercepts of a unit form cutting all three axes be expressed in figures, the intercept along the $b$ axis being considered as unity, we obtain the *axial ratio*. In Figs. 26 and 27, which represent a crystal of sulphur, the axial ratio is:

$$a : b : c = 0.8131 : 1 : 1.9034.$$

Every crystallized substance has its own axial ratio. This is illustrated by the ratios of three minerals crystallizing in the orthorhombic system.

| | |
|---|---|
| Aragonite, $CaCO_3$, | $a : b : c = 0.6228 : 1 : 0.7204$ |
| Anglesite, $PbSO_4$, | $a : b : c = 0.7852 : 1 : 1.2894$ |
| Topaz, $Al_2(F.OH)_2\ SiO_4$, | $a : b : c = 0.5281 : 1 : 0.9442$ |

In the hexagonal and tetragonal systems, since the horizontal axes are equal, *i.e.*, $a = b$, see page 4, the axial ratio is reduced to $a : c$; $a$ now being unity. Thus, the axial ratio of zircon ($ZrSiO_4$) which is tetragonal, may be expressed as follows: $a : c = 1 : 0.6404$; that of quartz ($SiO_2$), hexagonal, by $a : c = 1 : 1.0999$. Obviously, in the cubic system, page 4, where all three axes are equal, this is unnecessary.

However, in the monoclinic and triclinic systems, where either one or more axes intersect obliquely, it is not only necessary to give the axial ratio but also to indicate the values of the angles between the crystallographic axes. For example, gypsum ($CaSO_4.2H_2O$) crystallizes in the monoclinic system and has the following axial ratio:

$$a : b : c = 0.6896 : 1 : 0.4133$$

and the inclination of the $a$ axis to the $c$ is 98° 58′. This angle is known as $\beta$, Fig. 30.

In the triclinic system, since all axes are inclined to each other, it is also necessary to know the value of the three angles, which are located as shown in Fig. 31, viz.: $b \wedge c = \alpha$, $a \wedge c = \beta$, $a \wedge b = \gamma$.

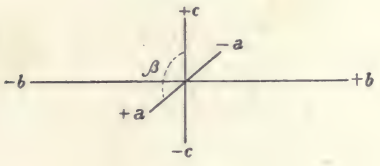



FIG. 30.

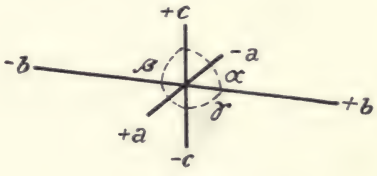



FIG. 31.

**Elements of Crystallization.**—The axial ratio and the angles showing the inclination of the axes are termed the *elements of crystallization.* Thus, the triclinic mineral albite ($NaAlSi_3O_8$) possesses the following elements crystallization:

$$a : b : c = 0.6330 : 1 : 0.5573.$$
$$\alpha = 94° 5′$$
$$\beta = 116° 27′$$
$$\gamma = 88° 7′$$

If the angles between the crystallographic axes equal 90°, they are not indicated. Therefore, in the tetragonal, hexagonal, and orthorhombic systems, the axial ratios alone constitute the elements of crystallization, while in the cubic system, there are no unknown elements.

**Rationality of Coefficients.**—The parametral ratio of any face may be expressed in general by $na : pb : mc$, where the coefficients $n$, $p$, $m$, are according to observation always rational. In Fig. 32, the inner bipyramid is assumed to be the fundamental form, page 5, with the following value of the intercepts: $oa = 1.256$, $ob = 1$, $oc = 0.752$.

Being a fundamental or unit form, the coefficients $n$, $p$, $m$, are obviously all equal to unity. The ratio is, hence, $a : b : c$.

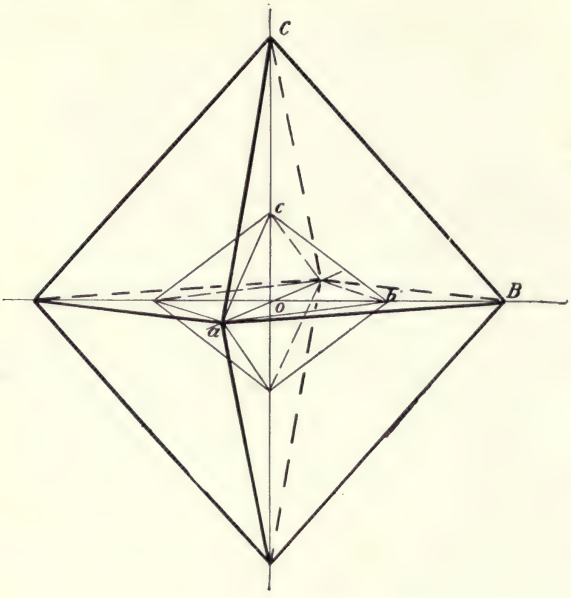



FIG. 32.

The outer bipyramid, however, possesses the intercepts, $oa = 1.256$, $oB = 2$, $oC = 2.256$. These lengths, divided by the unit lengths of each axis, as indicated above, determine the values of $n$, $p$, and $m$ for the outer bipyramid, namely:

$$n = \frac{1.256}{1.256} = 1; \quad p = \frac{2}{1} = 2;$$

$$m = \frac{2.256}{0.752} = 3.$$

FIG. 33.—Rene Hauy (1743–1822). Curator of mineralogy in the Museum of Natural History of Paris (1802–1822). Pioneer crystallographer and discoverer of many laws of crystallography, including that of the rationality of coefficients.

These values of $n$, $p$, and $m$, are, therefore, rational. Such values as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{6}$, $\frac{5}{3}$, or $\frac{2}{5}$ are also possible, but never $3.1416 +$, $2.6578 +$, $\sqrt{3}$, and so forth.

**Symbols.**—The parametral ratio of the plane ABM, Fig, 25, may be written as follows:

$$na : pb : mc.$$

But since, in this case, $n = 1$, $p = 1$, $m = 3$, the ratio becomes:

$$a : b : 3c.$$

If, however, the coefficients had the values $\frac{1}{2}$, $\frac{2}{3}$, and $\frac{4}{3}$, respectively, the ratio would then read:

$$\frac{1}{2}a : \frac{2}{3}b : \frac{4}{3}c.$$

This, when expressed in terms of $b$, becomes:

$$\frac{3}{4}a : b : 2c.$$

Hence, the ratio

$$na : b : mc$$

expresses the most general ratio or symbol for forms belonging to the orthorhombic, monoclinic, and triclinic systems. In the hexagonal and tetragonal systems, since the $a$ and $b$ axes are equal, this general symbol becomes,

$$a : na : mc.$$

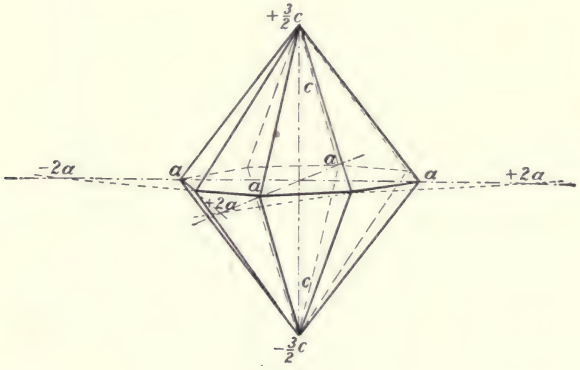



FIG. 34.

Figure 34 shows a form, the ditetragonal bipyramid, with the symbol $a:2a:\frac{3}{2}c$. In the cubic system, all three axes are equal and the general symbol reads,

$$a : na : ma.$$

The ratio $a : \infty a : \infty a$, for example, symbolizes a form in the cubic system consisting of six faces, which cut one axis and extend parallel to

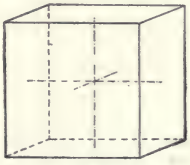


FIG. 35.

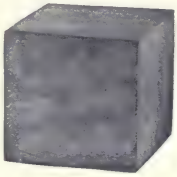


FIG. 36.

the other two. Such a form is the cube, Figs. 35 and 36. The ratio $a:2a:\infty a$ represents a form with twenty-four faces; each face cuts one axis at a unit's distance, the second at twice the distance, but extends parallel to the third axis. Figures 37 and 38 shows such a form, the tetrahexahe-

dron. This system of crystallographic notation is known as the Weiss system. These symbols are most readily understood, and well adapted for beginners.

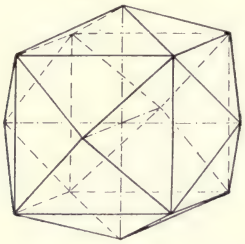


FIG. 37.

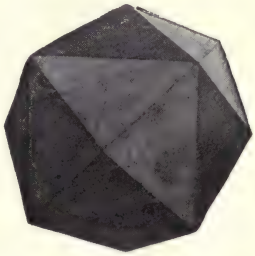


FIG. 38.

**Miller's Indices.**—In this system of notation the letters referring to the various crystallographic axes are not indicated, the values given being understood as referring to the *a*, *b*, and *c* axes respectively, page 3. The reciprocals of the Weiss parameters are reduced to the lowest common denominator. The numerators then constitute the Miller symbols, called *ndices*. For example, the reciprocals of the Weiss parameters $2a : b : 3c$ would be $\frac{1}{2}$, $\frac{1}{1}$, $\frac{1}{3}$. These, reduced to the lowest common denominator, are $\frac{3}{6}$, $\frac{6}{6}$, $\frac{2}{6}$. Hence, 3 6 2 constitute the corresponding Miller indices. These are read *three, six, two.*

FIG. 39.—Willian H. Miller (1801–1880). Professor of Mineralogy in the University of Cambridge (1832–1870).

A number of examples will make this system of notation clear. Thus, $a : \infty b : \infty c$, becomes 100; $2a : b : 5c$, 5.10.2; $a : a : 3c$, 331; $a : \infty a : 2c$, 201, and so forth. The Miller indices corresponding to the general ratios $a : na : ma$ and $na : b : mc$ are written *hkl.* The Miller indices are important because of their almost universal application in crystallographic investigations.

**Elements of Symmetry.**—The laws of symmetry find expression upon a crystal in the distribution of similar angles and faces. The presence, therefore, of planes, axes, or a center of symmetry—these are the *elements of symmetry*—is of great importance for the correct classification of a crystal.

**Planes of Symmetry.**—Any plane, which passes through the center of a crystal and divides it into two symmetrical parts, the one-half being the *mirror-image* of the other, is a *plane of symmetry.* Figure 40 shows a crystal of gypsum ($CaSO_4.2H_2O$) with its one plane of symmetry. Every plane of symmetry is parallel to some face, which is either *present* or *possible* upon the crystal.

It is sometimes convenient to designate planes of symmetry as *axial* and *diagonal*, or as *principal*, or *intermediate* planes. Figure 41 illustrates a crystal of the tetragonal system with five planes of symmetry.

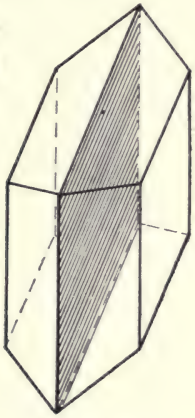


FIG. 40.

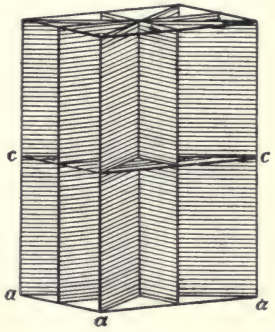



FIG. 41.

Plane *c* is the *horizontal axial* or *principal* plane. The vertical planes are the *vertical axial* (*a*) and *intermediate* planes of symmetry.

**Axes of Symmetry.**—The line, about which a crystal may be revolved as an axis so that after a definite angular revolution the crystal assumes exactly the same position in space which it originally had, is termed an *axis of symmetry*. Depending upon the rotation necessary, only four types of axes of symmetry are from the standpoint of crystallography possible.

(*a*) Those axes, about which the original position is reassumed after a revolution of 60°, are said to be axes of *hexagonal, six-fold*, or *six-count*[1] symmetry. Such axes may be indicated by the symbol ⬢. Figure 43 shows such an axis.

(*b*) If the original position is regained after the crystal is revolved through 90°, the axis is termed a *tetragonal, four-count*, or *four-fold* axis of symmetry. These axes are represented by ■, as illustrated in Fig. 44.

(*c*) Axes requiring an angular revolution of 120° are *trigonal, three-fold*, or *three-count* axes of symmetry and may be symbolized by ▲. Figure 45 illustrates this type of axis.

FIG. 42.—Victor Goldschmidt (1853—). Professor of mineralogy in the University of Heidelberg. Author of numerous contributions on crystallography.

(*d*) A *binary, two-fold*, or *two-count* axis necessitates a revolution through 180°. These are indicated by ⬬ in Fig. 44.

[1] Because in a complete revolution of 360° the position is reassumed six times.

**Center of Symmetry.**—That point within a crystal through which straight lines may be drawn, so that on either side of and at the same

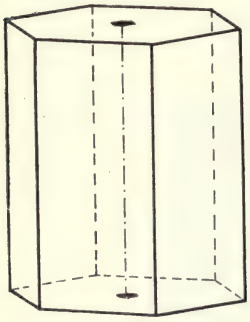


FIG. 43.

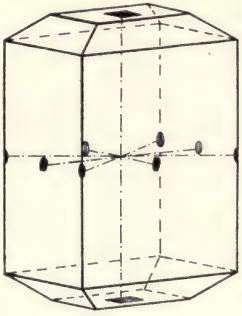


FIG. 44.

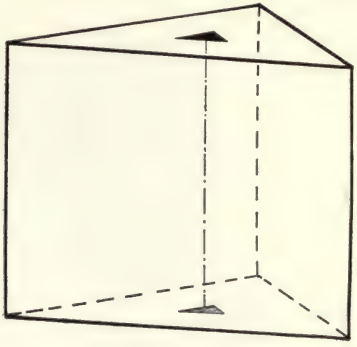


FIG. 45.

distance from it, similar portions of the crystal (faces, edges, angles, and so forth) are encountered, is a *center of symmetry*. Figure 46 has a center of symmetry—the other elements of symmetry are lacking.

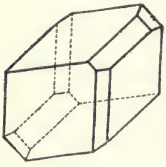


FIG. 46.

**Angular Position of Faces.**—Since crystals are oftentimes *misshapen* or *distorted*, page 2, it follows that the elements of symmetry are not always readily recognized. The *angular position* of the faces in respect to these elements is the essential feature, and not their distance or relative size. Figure 47 shows an ideal crystal of augite. Here, the presence of a plane of symmetry, an axis, and a center of

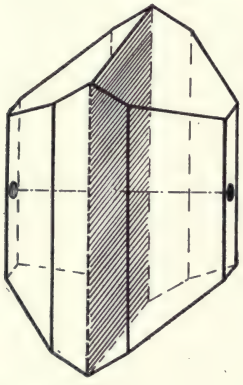


FIG. 47.

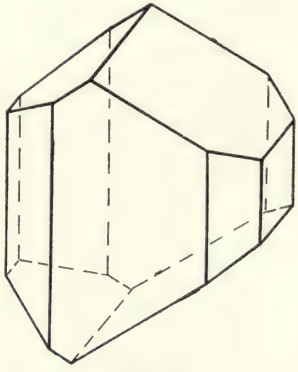


FIG. 48.

symmetry is obvious. Figure 48 shows a distorted crystal of the same mineral, possessing however exactly the same elements of symmetry, because the angular position of the faces is the same as in Fig. 47.

**Classes of Symmetry.**—Depending upon the elements of symmetry present, crystals may be divided into *thirty-two* distinct groups, called *classes of symmetry.*[1] Only forms which belong to the same class can occur in combination with each other. *A crystal system,* however, includes all those classes of symmetry which can be referred to the same type of crystallographic axes, page 4. The various elements of symmetry and, wherever possible, an important representative are given for each of the thirty-two classes in the tabular classification on page 372. Only 13 classes will be discussed in detail.

[1] Also termed *classes of crystals.*

# CHAPTER II

## CUBIC SYSTEM[1]

**Crystallographic Axes.**—All crystals which can be referred to three equal and perpendicular axes belong to cubic system. Figure 49 shows the axial cross. One axis is held vertically, a second extends from front to rear, and the third from right to left. These axes are all interchangeable, each being designated by *a*. Since there are no unknown elements of crystallization in this system (page 7), all substances, regardless of their chemical composition, crystallizing in this system with forms having the same parametral ratios must of necessity possess the same interfacial angles.

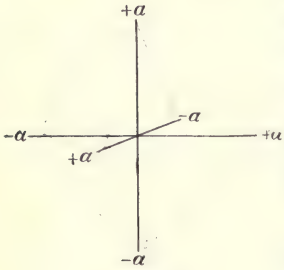


FIG. 49.

**Classes of Symmetry.**—The cubic system includes five groups or classes of symmetry. Beginning with the class of highest symmetry, they are:

(1) Hexoctahedral Class
(2) Hextetrahedral Class
(3) Dyakisdodecahedral Class
(4) Pentagonal icositetrahedral Class
(5) Tetrahedral pentagonal dodecahedral Class

Of these classes, the first three are the most important, and will be considered in detail.

### HEXOCTAHEDRAL CLASS[2]

**Elements of Symmetry.** (*a*) *Planes.*—Forms of this class are characterized by nine planes of symmetry. Three of these are parallel to the planes of the crystallographic axes and, hence, perpendicular to each other. They are the axial planes of symmetry. They divide space into eight equal parts called *octants*. The six other planes are each parallel to one of the crystallographic axes and bisect the angles between the other two. These are termed the diagonal planes of symmetry. By them space is divided into twenty-four equal parts. The nine planes together divide space into forty-eight equal sections. Figures 50 and 51 illustrate the location of the axial and diagonal planes, respectively.

(*b*) *Axes.*—The intersection lines of the three axial planes of symmetry give rise to the three *tetragonal* axes of symmetry. These are the

[1] Also termed the regular, isometric, tesseral, or tessular system.
[2] Termed by Dana the *normal group*.

crystallographic axes, as illustrated by Fig. 52. The four axes equally inclined to the crystallographic axes are of *trigonal* symmetry, as shown by

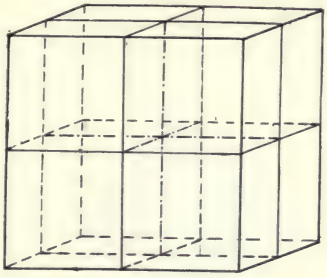


FIG. 50.

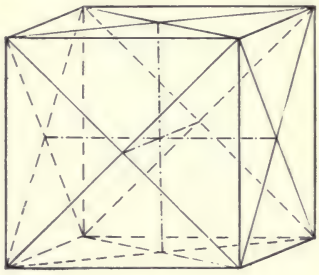


FIG. 51.

Fig. 53. There are also six axes of *binary* symmetry. These lie in the axial planes of symmetry and bisect the angles between the crystallo-

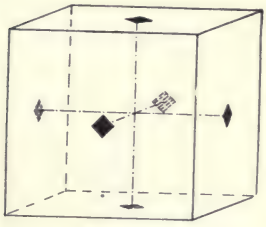


FIG. 52.

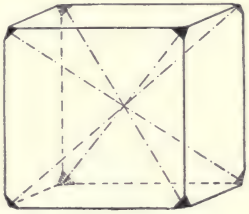


FIG. 53.

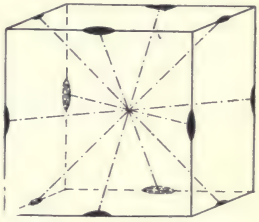


FIG. 54.

graphic axes. Their location is indicated in Fig. 54. These thirteen axes of symmetry may be indicated as follows:

$$3\,\blacksquare + 4\,\blacktriangle + 6\,\bullet = 13.$$

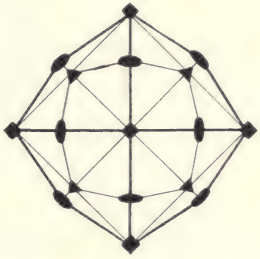


FIG. 55.

(*c*) *Center.*—The forms of this class also possess this element of symmetry. Hence, all planes have parallel counter-planes.

The projection of the most general form of this class upon a plane perpendicular to the vertical axis, *i.e*, in this case an axial plane of symmetry, shows the symmetry relations,[1] Fig. 55.

[1] The heavy lines indicate edges through which axial planes of symmetry pass. The light, full lines show the location of the diagonal planes, while dashed lines would indicate the absence of planes.

**Octahedron.**—As the name implies, this form consists of eight faces. Each face is equally inclined to the crystallographic axes. Hence, the parametral ratio may be written $(a : a : a)$, which according to Miller would be $\{111\}$. The faces intersect at an angle of 109° 28′ 16″ and in the ideal form, Figs. 56 and 57, are equal, equilateral triangles.

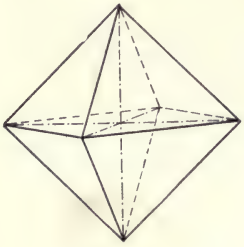


Fig. 56.

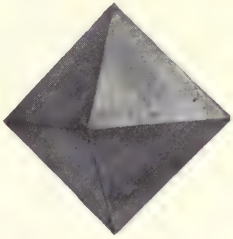


Fig. 57.

The crystallographic axes and, hence, the axes of tetragonal symmetry pass through the tetrahedral angles. The four trigonal axes join the centers of opposite faces, while the six binary axes bisect the twelve edges.

**Dodecahedron.**—This form consists of twelve faces, each cutting two of the crystallographic axes at the same distance, but extending parallel to the third. The symbols are, therefore, $(a : a : \infty a)$, or $\{110\}$. In the ideal form, Figs. 58 and 59, each face is a rhombus and, hence, the form is often termed the *rhombic dodecahedron*.

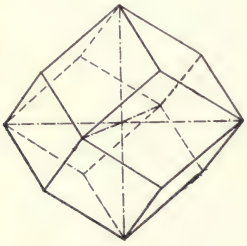


Fig. 58.

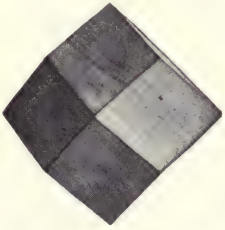


Fig. 59.

The crystallographic axes pass through the tetrahedral angles, the trigonal axes join opposite trihedral angles, and the binary axes the centers of opposite faces. It follows, therefore, that the faces are parallel to the diagonal planes of symmetry.

**Hexahedron or Cube.**—The faces of this form cut one axis and are parallel to the other two. This is expressed by $(a : \infty a : \infty a)$, $\{100\}$. Six such faces are possible and when the development is ideal, Figs. 60 and 61, each is a square.

The crystallographic axes pass through the centers of the faces.

The trigonal axes of symmetry join opposite trihedral angles, while the binary axes bisect the twelve edges. Compare Figs. 52, 53 and 54.

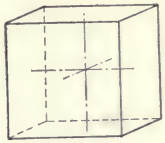


FIG. 60.

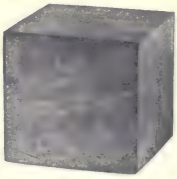


FIG. 61.

**Trigonal Trisoctahedron.**[1]—The faces of this form cut two crystallographic axes at equal distances, the third at a greater distance, *ma*. The coefficient *m* is some rational value greater than one but less than infinity. The ratio is $(a : a : ma)$ and it requires twenty-four such faces to enclose space. The Miller symbols are $\{hhl\}$, where *h* is greater than *l*. Because the general outline of this form is similar to that of the octahedron, each face of which in the ideal forms is replaced by three equal isosceles triangles, it is termed the *trigonal trisoctahedron*, Figs. 62 and 63, $(a : a : 2a)$, $\{221\}$, and 64, $(a : a : 3a)$, $\{331\}$.

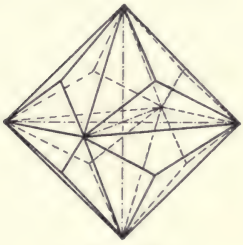


FIG. 62.

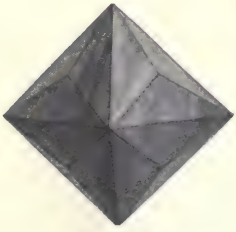


FIG. 63.

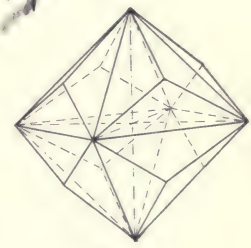


FIG. 64.

The crystallographic axes join opposite octahedral angles. The trigonal axes pass through the trihedral angles and the six binary axes bisect the twelve long edges.

**Tetragonal Trisoctahedron.**[2]—This form consists of twenty-four faces, each cutting one axis at a unit's distance and the other two at greater but equal distances, *ma*. The value of *m*, is, as above, $m > 1 < \infty$. The symbols are, therefore, $(a : ma : ma)$, or $\{hll\}$, $h > l$. The ideal forms, Figs. 65 and 66, $(a : 2a : 2a)$, $\{211\}$, and 67, $(a : 4a : 4a)$, $\{411\}$, bear some resemblance to the octahedron, each face of which has been replaced by three four-sided faces, trapeziums, of equal size. The form is, therefore, termed the *tetragonal trisoctahedron*. The six tetrahedral angles[3] *a* indicate the position of the crystallographic axes. The

[1] Also known as the trisoctahedron.

[2] Also termed the trapezohedron, icositetrahedron, and leucitohedron.

[3] With four equal edges.

trigonal axes of symmetry join opposite trihedral angles, while those of binary symmetry connect the tetrahedral angles[1] *b*.

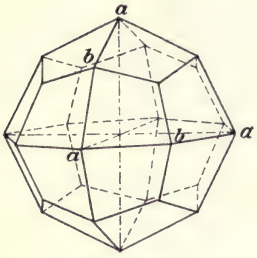



FIG. 65.

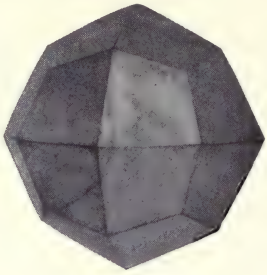


FIG. 66.

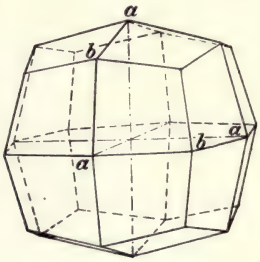



FIG. 67.

**Tetrahexahedron.**—In this form the faces cut one axis at a unit's distance, the second at the distance *ma*, where $m > 1 < \infty$, and extend parallel to the third axis. The symbols are, therefore, $(a : ma : \infty a)$, or $\{hko\}$. The twenty-four faces in the ideal forms, Figs. 68 and 69, $(a: 2a: \propto a)$, $\{210\}$, and 70, $(a:4a: \infty a)$, $\{410\}$, are equal isosceles triangles. Since this form may be considered as a cube, whose faces have been replaced by tetragonal pyramids, it is often called the *pyramid cube* or *tetrahexahedron*.

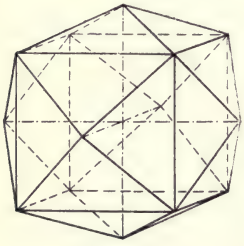


FIG. 68.

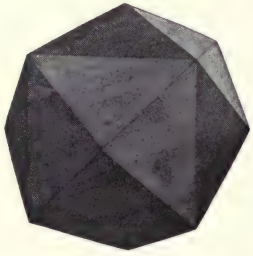


FIG. 69.

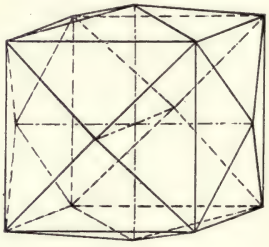


FIG. 70.

The crystallographic axes are located by the six tetrahedral angles. The axes of trigonal symmetry pass through opposite hexahedral angles, while the binary axes bisect the long edges.

**Hexoctahedron.**—As is indicated by the name, this form is bounded by forty-eight faces. Each cuts one crystallographic axis at a unit's distance, the other two at greater but unequal distances, *na* and *ma*, respectively; *n* is less than *m*, the value of *m* being, as heretofore, $m > 1 < \infty$. Hence, the symbols may be written $(a : na : ma)$, or, $\{hkl\}$. Figures 71 and 72 $(a : 3/2a : 3a)$, $\{321\}$, and 73, $(a : 5/3a : 5a)$ $\{531\}$, show ideal forms, the faces being scalene triangles of the same size.

[1] These have two pairs of equal edges.

The crystallographic axes pass through the octahedral angles, while the hexahedral angles locate those of trigonal symmetry. The binary axes pass through opposite tetrahedral angles.

The seven forms just described are the only ones possible in this class.

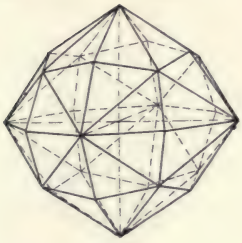


FIG. 71.

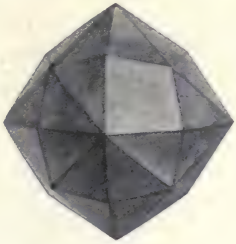


FIG. 72.

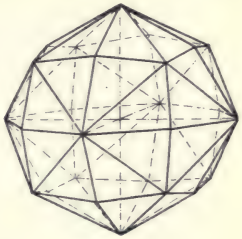


FIG. 73.

**Summary.**—The following table gives a summary of the most important features of the hexoctahedral class.

| Symmetry | Planes | | Axes | | | Center |
|---|---|---|---|---|---|---|
| | Axial | Diagonal | ■ | ▲ | ⬬ | |
| | 3 | 6 | 3 | 4 | 6 | 1 |

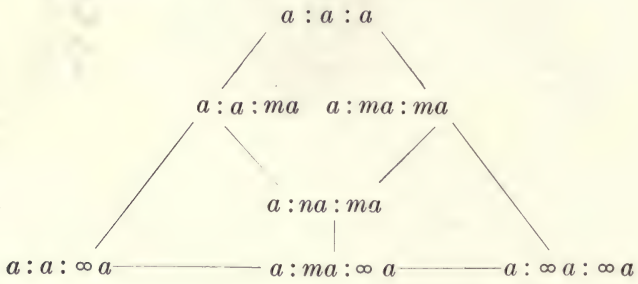
| Forms | Symbols | | Faces | Solid angles | | | |
|---|---|---|---|---|---|---|---|
| | Weiss | Miller | | Trihedral | Tetrahedral | Hexahedral | Octahedral |
| Octahedron | $a:a:a$ | {111} | 8 | – | 6 | – | – |
| Dodecahedron | $a:a:\infty a$ | {110} | 12 | 8 | 6 | – | – |
| Hexahedron | $a:\infty a:\infty a$ | {100} | 6 | 8 | — | – | – |
| Trigonal trisoctahedron | $a:a:ma$ | {*hhl*} | 24 | 8 | — | – | 6 |
| Tetragonal trisoctahedron | $a:ma:ma$ | {*hll*} | 24 | 8 | 6[1]+12[2] | – | – |
| Tetrahexahedron | $a:ma:\infty a$ | {*hko*} | 24 | – | 6 | 8 | – |
| Hexoctahedron | $a:na:ma$ | {*hkl*} | 48 | – | 12 | 8 | 6 |

[1] These have four equal edges.

[2] Two pairs of two equal edges each.

From this tabulation we see that the ratios of the octahedron, dodecahedron, and hexahedron contain no variables and, hence, each is represented by but one form. These are often called *singular* or *fixed* forms. The other ratios, however, contain either one or two variables and, therefore, each represents a series of forms. Compare Figs. 62 to 73.

**Relationship of Forms.**—The relationship existing between the above forms is well expressed by the following diagram:




The three fixed forms are placed at the corners of the triangle and, as is obvious, must be considered as the limiting forms of the others. For example, the value of $m$ in the trigonal trisoctahedron $(a : a : ma)$ varies between unity and infinity, page 17. Hence, it follows that the octahedron and dodecahedron are its limiting forms. The tetragonal trisoctahedron $(a : ma : ma)$ similarly passes over into the octahedron or cube, depending upon the value of $m$. The limiting forms are, therefore, in every case readily recognized. Those forms, which are on the sides of the triangle,[1] lie in the same zone, that is, their intersection lines are parallel.

**Combinations.**—The following figures illustrate some of the combinations of the forms, which are observed most frequently.

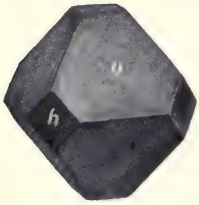



FIG. 74.

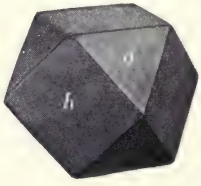



FIG. 75.

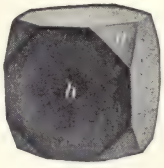



FIG. 76.

Figures 74, 75, and 76, $o = (a : a : a)$, $\{111\}$; $h = (a : \infty a : \infty a)$, $\{100\}$. This combination is frequently observed on galena (PbS). In Fig. 74, the octahedron predominates, in Fig. 75 both forms are equally developed, while in Fig. 76 the cube is the predominant form.

Figure 77, $o = (a : a : a)$, $\{111\}$; $d = (a : a : \infty a)$, $\{110\}$. Observed

[1] For example, the octahedron, trigonal trisoctahedron, and dodecahedron.

on spinel ($Mg(AlO_2)_2$), magnetite ($Fe(FeO_2)_2$), and franklinite, $(Fe,ZnMn)(FeO_2)_2$.

Figure 78, $h = (a : \infty a : \infty a)$, $\{100\}$; $d = (a : a : \infty a)$, $\{110\}$.

Frequently observed on galena (PbS) and fluorite ($CaF_2$).

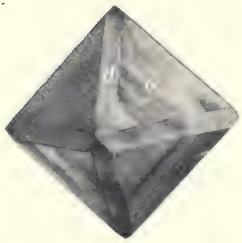



FIG. 77.

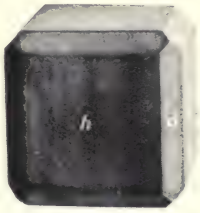



FIG. 78.

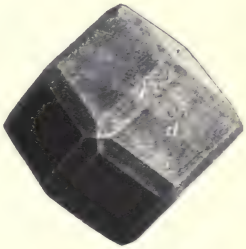



FIG. 79.

Figure 79, $d = (a : a : \infty a)$, $\{110\}$; $i = (a : 2a : 2a)$, $\{211\}$. This is a frequent combination on garnet ($R_3''R_2'''Si_4O_{12}$).

Figures 80, 81, and 82, $h = (a : \infty a : \infty a)$, $\{100\}$; $o = (a : a : a)$, $\{111\}$; $d = (a : a : \infty a)$ $\{110\}$. Also observed on galena (PbS).

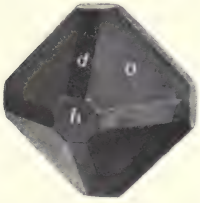



FIG. 80.

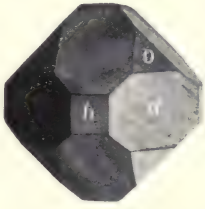



FIG. 81.

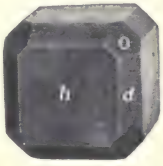



FIG. 82.

Figure 83, $h = (a : \infty a : \infty a)$, $\{100\}$; $e = (a : 2a : \infty a)$, $\{210\}$. Observed on copper (Cu), fluorite ($CaF_2$), and halite (NaCl).

Figure 84, $h = (a : \infty a : \infty a)$, $\{100\}$; $i = (a : 2a : 2a)$, $\{211\}$. Observed on analcite ($NaAlSi_2O_6$, $H_2O$) and argentite ($Ag_2S$).

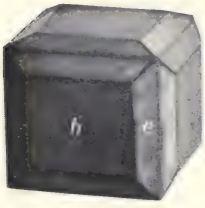



FIG. 83.

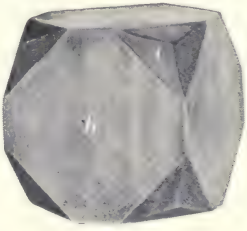



FIG. 84.

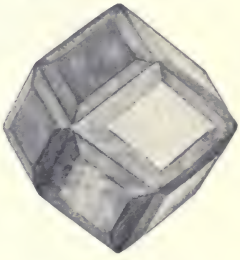


FIG. 85.

Figure 85, $d = (a : a : \infty a)$, $\{110\}$; $s = (a : 3/2a : 3a)$, $\{321\}$. Sometimes observed on garnet ($R_3''R_2'''Si_4O_{12}$).

## HEXTETRAHEDRAL CLASS[1]

**Elements of Symmetry.**—The elements of symmetry of this class consist of six diagonal planes, and four trigonal and three binary axes. The trigonal axes are polar in character. The crystallographic axes possess binary symmetry. The diagonal planes of symmetry are easily located since they pass through the edges of the various forms of this class. The symmetry relations are shown in Fig. 86. The polarity of the trigonal axes and absence of the axial planes of symmetry are emphasized by the shading of opposite octants. In this class, there are four new forms which differ morphologically from those having the same ratios in the hexoctahedral class, namely, tetrahedrons, tetragonal tristetrahedrons, trigonal tristetrahedrons, and hextetrahedrons. Of these forms the tetrahedrons are the most important.

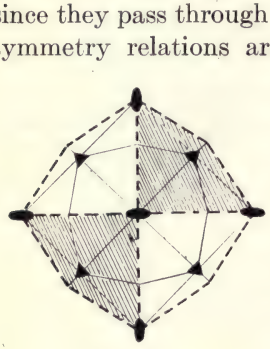


FIG. 86.

**Tetrahedrons.**—These are bounded by four equilateral triangles intersecting at equal angles

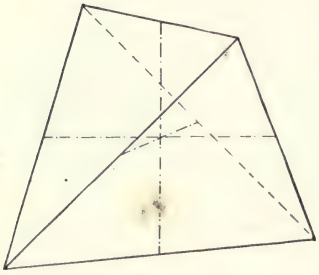


FIG. 87.

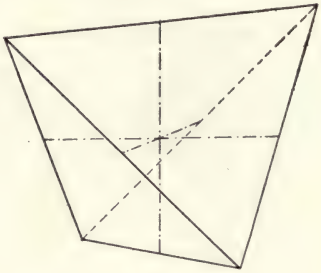


FIG. 88.

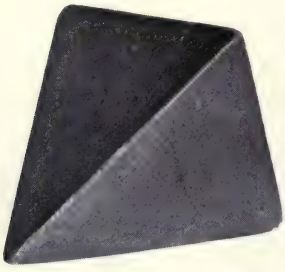


FIG. 89.

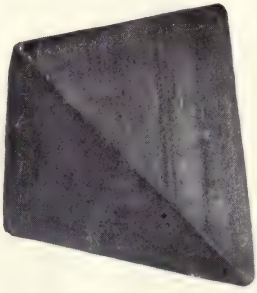


FIG. 90.

of 70° 32′. Each face is equally inclined to the crystallographic axes and consequently the symbols are the same as for the octahedron (page 16), namely $\pm(a:a:a)$ or $\{111\}$ and $\{1\bar{1}1\}$ There are two tetra-

[1] The *tetrahedral group* of Dana.

hedrons possible and their difference depends upon the positions they occupy in space, as illustrated in Figs. 87 to 90. If the upper face to the front lies in the positive octant, the form is designated as *positive* (Figs. 88 and 90), if not, it is *negative* (Figs. 87 and 89). The forms are said to be *congruent*, for a positive form may be brought into the position of a negative by rotating through an angle of 90° and vice versa.

The crystallographic axes pass through the centers of the edges and possess binary symmetry. The trigonal axes pass from the trihedral angles to the centers of opposite faces, and are *polar* in character.

**Tetragonal Tristetrahedrons.**—These forms possess a tetrahedral habit and are bounded by twelve faces, which in the ideal development are similar trapeziums. Each face has four angles. Plus and minus forms are possible. The symbols are the same as for the trigonal trisoctahedron, page 17, namely, $\pm(a : a : ma)$ or $\{hhl\}$ and $\{h\bar{h}l\}$. The differentiation between positive and negative forms is analogous to that referred to under tetrahedrons. Figure 92 represents a *positive* form and Fig. 91 a *negative*. These forms are some times called *deltoids* or *deltoid dodecahedrons*.

The crystallographic axes pass through opposite tetrahedral angles, while the axes of trigonal symmetry join opposite trihedral angles, one of which is acute, the other obtuse.

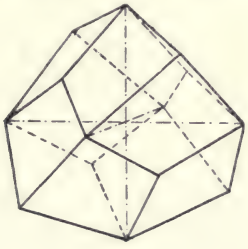


FIG. 91.

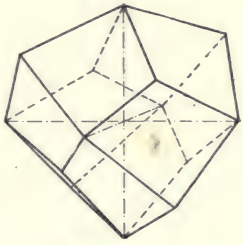


FIG. 92.

**Trigonal Tristetrahedrons.**—These are two congruent forms bounded by twelve similar isosceles triangles, Figs. 93 and 94. The habit is tetrahedral, and the forms might be considered as tetrahedrons whose faces

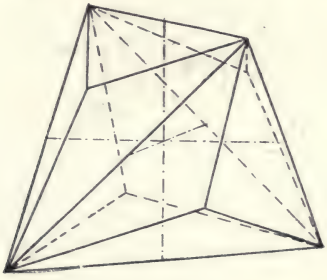


FIG. 93.

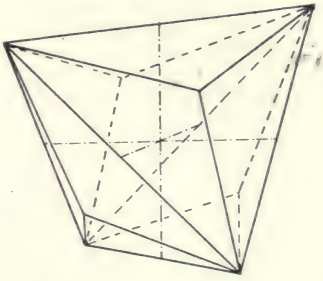


FIG. 94.

have been replaced by trigonal pyramids. They are sometimes called *pyramid tetrahedrons* or *trigonal dodecahedrons.* The symbols are analogous to those of the tetragonal trisoctahedron, page 17, namely, $\pm(a : ma : ma)$ or $\{hll\}$ and $\{h\bar{l}l\}$. Figure 94 illustrates the *positive* position and Fig. 93 the *negative.*

The crystallographic axes bisect the long edges. The trigonal axes pass from the trihedral angles to the opposite hexahedral.

**Hextetrahedrons.**—When these forms are ideally developed, they possess a tetrahedral habit and are bounded by twenty-four similar scalene triangles. They are congruent and hence designated as *positive,* Fig. 96, and negative, Fig. 95. The symbols are of the same character as those of the hexoctahedron, page 18, namely, $\pm(a : na : ma)$ or $\{hkl\}$ and $\{h\bar{k}l\}$.

The crystallographic axes connect opposite tetrahedral angles. The trigonal axes of symmetry pass through opposite hexahedral angles, one of which is more obtuse than the other.

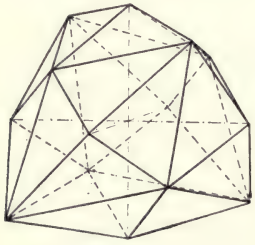


Fig. 95.

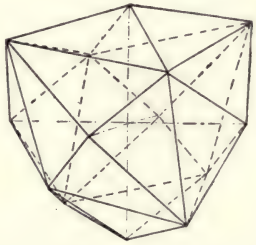


Fig. 96.

**Other Forms.**—The hexahedron, dodecahedron, and tetrahexahedron are morphologically exactly similar to those of the hexoctahedral class. Their symmetry is however of a lower grade. This is not recognized on models. On crystals, however, the luster, surface striations, and form and position of *etch figures* reveal the lower grade of symmetry.*

* When crystals are subjected to the action of some solvent for a short time, small depressions or elevations, the so-called *etch figures,* appear. Being dependent upon the internal molecular structure, their form and position indicate the symmetry of the

Fig. 97.

Fig. 98.

crystal. For instance, Fig. 97 shows the etch figures on a crystal (cube) of halite, NaCl. Here, it is evident, that the symmetry of the figures with respect to that of the cube is such as to place the crystal in the hexoctahedral class. Figure 98 represents a cube of sylvite, KCl, which geometrically does not differ from the crystal of halite. A lower grade of symmetry is, however, revealed by the position of the etch

Naturally when these forms occur in combination with those which are morphologically new, the lower grade of symmetry of this class is at once apparent.

**Summary.**—The following table shows the important features of the forms of this class of symmetry.

| Symmetry | Planes | | Axes | | | Center |
|---|---|---|---|---|---|---|
| | Axial | Diagonal | ■ | ▲ | ⬬ | |
| | 0 | 6 | 0 | 4 (Polar) | 3 | 0 |

| Forms | Symbols | | Faces | Solid angles | | |
|---|---|---|---|---|---|---|
| | Weiss | Miller | | Trihedral | Tetrahedral | Hexahedral |
| Tetrahedrons | $\pm a:a:a$ | $\{111\}$ $\{1\bar{1}1\}$ | 4 | 4 | — | — |
| Tetragonal tristetrahedrons | $\pm a:a:ma$ | $\{hhl\}$ $\{h\bar{h}l\}$ | 12 | 4+4 | 6 | — |
| Trigonal tristetrahedrons | $\pm a:ma:ma$ | $\{hll\}$ $\{h\bar{l}l\}$ | 12 | 4 | — | 4 |
| Hextetrahedrons | $\pm a:na:ma$ | $\{hkl\}$ $\{h\bar{k}l\}$ | 24 | — | 6 | 4 + 4 |
| Dodecahedron | $a:a:\infty a$ | $\{110\}$ | Morphologically the same as in the hexoctahedral class. | | | |
| Tetrahexahedron | $a:ma:\infty a$ | $\{hko\}$ | | | | |
| Hexahedron | $a:\infty a:\infty a$ | $\{100\}$ | | | | |

figures. This crystal belongs to the pentagonal icositetrahedral class, page 14, for no planes of symmetry can be passed through these figures, which at the same time are planes of symmetry of the cube, as is the case with the crystal of halite.

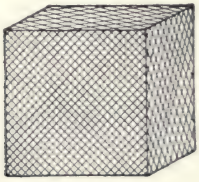


FIG. 99.

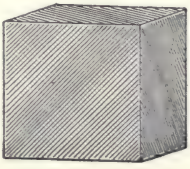


FIG. 100.

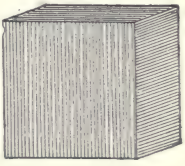


FIG. 101.

Figures 99, 100, and 101 show three cubes representing crystals of fluorite, $CaF_2$ (Fig. 99), sphalerite, ZnS (Fig. 100), and pyrite, $FeS_2$ (Fig. 101). From the char-

**Combinations.**—Some of the more common combinations are illustrated by the following figures:

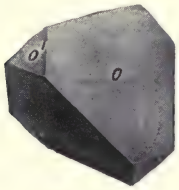



FIG. 102.

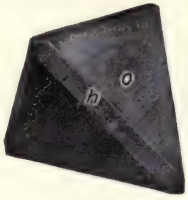



FIG. 103.

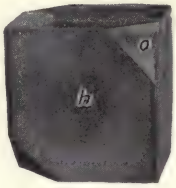



FIG. 104.

Figure 102, $o = (a:a:a), \{111\}; o' = -(a:a:a), \{1\bar{1}1\}$. This combination is common on sphalerite (ZnS).

Figure 103, $h = (a:\infty a:\infty a), \{100\}; o = (a:a:a), \{111\}$. Observed on sphalerite (ZnS) and tetrahedrite $(Cu_2, Fe, Zn)_4(As, Sb)_2S_7$.

Figure 104, $o = (a:a:a), \{111\}; h = (a:\infty a:\infty a), \{100\}$. Observed on boracite $(Mg_7Cl_2C_{16}O_{30})$ and tetrahedrite $(Cu_2,Fe,Zn)_4(As,Sb)_2S_7$.

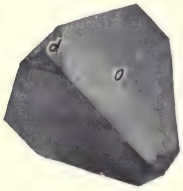



FIG. 105.

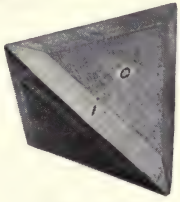



FIG. 106.

FIG. 107.

Figures 105, 106, and 107, $o = (a:a:a), \{111\}; i = (a:2a:2a), \{211\}; d = (a:a:\infty a), \{110\}$. Frequent on tetrahedrite $(Cu_2, Fe, Zn)_4(As, Sb)_2S_7$.

## DYAKISDODECAHEDRAL CLASS

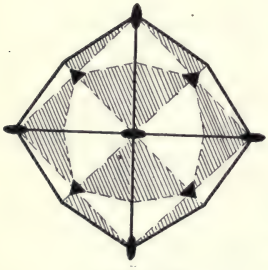


FIG. 108.

**Elements of Symmetry.**—The elements of symmetry of this class consist of three axial planes, three binary and four trigonal axes, and the center of symmetry. The crystallographic axes possess binary symmetry. Figure 108 shows the symmetry relations.

There are two new forms in this class which differ morphologically from those thus far considered, namely, the pyritohedrons and dyakisdodecahedrons.

---

acter and position of the striations on the faces of these cubes, it is at once recognized that through Fig. 99, nine planes of symmetry may be passed, through Fig. 100 six, and through Fig. 101 only three. That is, the striations indicate clearly that fluorite has the symmetry of the hexoctahedral class, sphalerite of the hextetrahedral class, and pyrite of the dyakisdodecahedral class.

**Pyritohedrons.**—The symbols of these forms are analogous to those of the tetrahexahedron, page 18, namely, $\pm(a : ma : \infty a)$ or $\{hko\}$ and $\{kho\}$. There are two congruent forms possible, Fig. 110, *positive*, and Fig. 109, *negative*.

Each form is bounded by twelve similar faces. The faces are unequilateral pentagons, four sides of which are equal. The crystallographic axes possess binary symmetry and bisects the six long edges. The trigonal axes pass through the trihedral angles, the edges of which are of equal lengths. The three planes of symmetry pass through the long

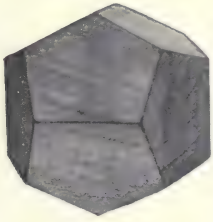


FIG. 109.

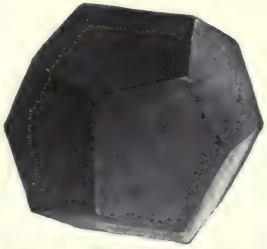


FIG. 110.

edges. These forms are termed pyritohedrons because they are very frequently observed upon the very common mineral pyrite, $FeS_2$. They are also designated as *pentagonal dodecahedrons*.[1]

**Dyakisdodecahedrons.**—These are congruent forms bounded by twenty-four similar trapeziums and possess symbols corresponding to the hexoctahedron, namely, $\pm(a : na : ma)$ or $\{hkl\}$ and $\{hlk\}$. They are some times termed *didodecahedrons* or *diploids*. Figure 112 shows a *positive* form and Fig. 111 a *negative*. The crystallographic axes pass

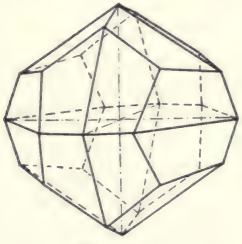


FIG. 111.

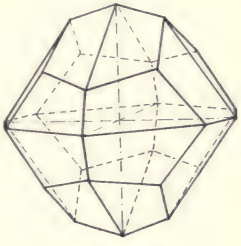


FIG. 112.

through the six tetrahedral angles possessing two pairs of equal edges. The trigonal axes join opposite trihedral angles. The three planes of symmetry pass through the continuous edges.

[1] The regular pentagonal dodecahedron of geometry, bounded by equilateral pentagons intersecting in equal edges and angles is crystallographically an impossible form, the value of $m$ being $\frac{1+\sqrt{5}}{2}$, which is irrational.

**Other Forms:** The hexahedron, octahedron, dodecahedron, trigonal trisoctahedron, and tetragonal trisoctahedron occur in this class with the same morphological development as in the hexoctahedral class. They, however, possess a lower grade of symmetry. If they occur independently, the lower grade of symmetry may be recognized by etch figures or peculiar physical characteristics of the faces. (See page 24.)

**Summary.**—In the following table, the important features of the various forms of this class are given.

| Symmetry | Planes | | Axes | | | Center |
|---|---|---|---|---|---|---|
| | Axial | Diagonal | ■ | ▲ | ⬬ | |
| | 3 | 0 | 0 | 4 | 3 | 1 |

| Forms | Symbols | | Faces | Solid angles | | | |
|---|---|---|---|---|---|---|---|
| | | | | Trihedral | | Tetrahedral | |
| | Weiss | Miller | | 3 Equal Edges | 2 + 1 Edges | 2 + 2 Edges | 2 + 1 + 1 Edges |
| Pyritohedrons | $\pm a : ma : \infty a$ | $\{hko\}$ $\{kho\}$ | 12 | 8 | 12 | — | — |
| Dyakisdodecahedrons | $\pm a : na : ma$ | $\{hkl\}$ $\{hlk\}$ | 24 | 8 | – | 6 | 12 |
| Octahedron | $a : a : a$ | $\{111\}$ | Morphologically the same as in the hexoctahedral class. | | | | |
| Dodecahedron | $a : a : \infty a$ | $\{110\}$ | | | | | |
| Hexahedron | $a : \infty a : \infty a$ | $\{100\}$ | | | | | |
| Trigonal trisoctahedron | $a : a : ma$ | $\{hhl\}$ | | | | | |
| Tetragonal trisoctahedron | $a : ma : ma$ | $\{hll\}$ | | | | | |

**Combinations.**—The accompanying figures show some combinations of the forms of this class.

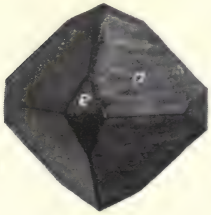



Fig. 113.

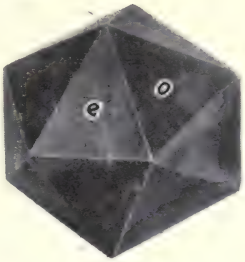



Fig. 114.

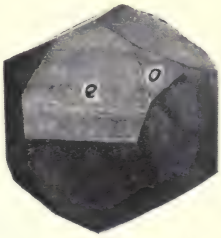



Fig. 115.

Fig. 116.

Fig. 117.

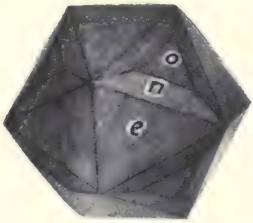



Fig. 118.

Figures 113 to 118, $o = (a : a : a)$, $\{111\}$; $e = (a : ma : \infty a)$, $\{210\}$; $h = (a : \infty a : \infty a)$, $\{100\}$; $n = (a : \frac{3}{2}a : 3a)$, $\{321\}$. These combinations are frequently observed on pyrite, $FeS_2$.

## CHAPTER III

## HEXAGONAL SYSTEM

**Crystallographic Axes.**—This system includes all crystals which can be referred to four axes, three of which are equal and lie in an horizontal plane, and intersect each other at an angle of 60°. These are termed the *lateral* axes, being designated by the letter *a*. These axes are interchangeable. The fourth, or *principal* axis is perpendicular to the plane of the lateral axes and is termed the *c* axis. It may be longer or shorter than the lateral axes. The three equal axes, which bisect the angles between the lateral axes, are the *intermediate* axes. These may be designated by *b*. Figure 119 shows an axial cross of this system.

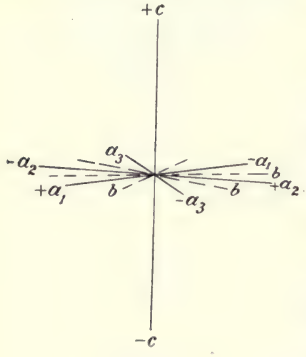


FIG. 119.

In reading crystals of the hexagonal system, it is customary to hold the *c* axis vertically, letting one of the lateral or *a* axes extend from right to left. The extremities of the lateral axes are alternately characterized as plus and minus, see Fig. 119. In referring a form to the crystallographic axes, it is common practice to consider them in the following order; $a_1$ first, then $a_2$, thirdly $a_3$, and lastly the *c* axis. The symbols always refer to them in this order. It is also to be noted that in following this order, one of the lateral axes will always be preceded by a minus sign.

Since the lengths of the *a* and *c* axes differ, it is necessary to assume for each substance crystallizing in this system a fundamental form, whose intercepts are taken as representing the unit lengths of the lateral and principal axes, respectively. The ratio, which exists between the lengths of these axes is called the *axial* ratio and is always an irrational value, the *a* axis being assumed as unity, page 6.

**Classes of Symmetry.**—The hexagonal system includes a larger number of classes of symmetry than any other system, namely, twelve. Beginning with the class of highest symmetry, they are:

* 1. Dihexagonal bipyramidal class
* 2. Dihexagonal pyramidal class
‡ 3. Ditrigonal bipyramidal class
‡* 4. Ditrigonal scalenohedral class

* 5. Hexagonal bipyramidal class
6. Hexagonal trapezohedral class
‡* 7. Ditrigonal pyramidal class
8. Hexagonal pyramidal class
‡† 9. Trigonal bipyramidal class
‡*10. Trigonal trapezohedral class
‡*11. Trigonal rhombohedral class
‡ 12. Trigonal pyramidal class

Those classes marked with an* are the most important, for nearly all of the crystals of this system belong to some one of them. No representative has as yet been observed for the class marked by †. Those marked ‡ are often grouped together and form the *trigonal* system. Only classes 1, 4, 5, 7, and 10 will be discussed in detail. A fairly comprehensive idea of the hexagonal system, amply sufficient for beginning students, may be obtained from a consideration of classes 1 and 4.

### DIHEXAGONAL BIPYRAMIDAL CLASS[1]

**Symmetry.**—This class possesses the highest grade of symmetry of any in the hexagonal system.

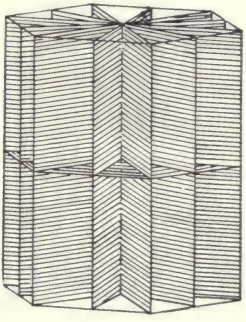


FIG. 120.

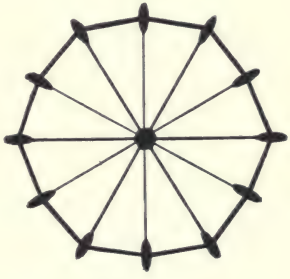


FIG. 121.

(*a*) *Planes.*—In all there are *seven* planes of symmetry. One of these, the *horizonal axial* or *principal* plane, is the plane of the horizontal axes. The other planes are vertical and are divided into two series of three each, which are termed the *vertical axial* and the *intermediate*, respectively. They intersect at angles of 60°. The intermediate planes bisect the angles between the vertical axial.

The four axial planes divide space into twelve equal parts, called *dodecants;* the seven planes, however, into twenty-four parts, Fig. 120.

These planes are often designated as follows:

1 Horizontal Axial + 3 Vertical Axial + 3 Vertical Intermediate = 7 Planes.

[1] The *normal group* of Dana.

(*b*) *Axes.*—The *c* axis is an axis of *hexagonal* symmetry, while the lateral and intermediate axes possess *binary* symmetry. These axes are often indicated, thus,

$$1 \bullet\!\!\!\!\bullet + 3 \bullet\!\!\!\!\bullet + 3 \bullet\!\!\!\!\bullet = 7 \text{ axes.}$$

(*c*) *Center.*—This element of symmetry is also present, requiring every face to have a parallel counter-face. Figure 121, the projection of the most complicated form upon a plane perpendicular to the vertical axis, shows the elements of symmetry of this class.

**Hexagonal Bipyramid of the First Order.**—From Fig. 122, it is obvious that any plane which cuts any two adjacent lateral axes at the unit distance from the center must extend parallel to the third. If such a plane be assumed to cut the *c* axis at its unit length from the center, the parametral ratio would then be

$$a_1 : \infty a_2 : a_3 : c.$$

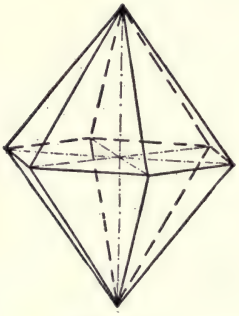


FIG. 122.

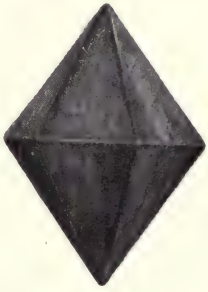


FIG. 123.

According to the above elements of symmetry, twelve planes possessing this ratio are possible. They enclose space and give rise to the form termed the *hexagonal bipyramid*[1] *of the first order*, Figs. 122 and 123. In the ideal form, the faces are all equal, isosceles triangles. The symbols are $(a : \infty a : a : c)$, $\{10\bar{1}1\}$.[2] Because the intercepts along the *c* and two lateral axes are taken as units, such bipyramids are also known as *fundamental* or *unit* bipyramids, page 5.

Planes are, however, possible which cut the two lateral axes at the unit distances, but intercept the *c* axis at the distance *mc*, the coefficient *m* being some rational value smaller or greater than 1, see page 7. Such bipyramids, according as *m* is greater or less than unity, are more acute or obtuse than the fundamental form. They are termed *modified* hexagonal bipyramids of the first order. Their symbols are

$$(a : \infty a : a : mc) \text{ or } \{ho\bar{h}l\}, \text{ where } m = \frac{h}{l}, \text{ also } m > 0 < \infty.$$

[1] Since these are really double pyramids, the term *bipyramid* is employed.

[2] In this system it is advantageous to employ the indices as modified by Bravais ($hi\bar{k}l$) rather than those of Miller, who uses but three.

The principal axis passes through the hexahedral angles, the lateral axes join tetrahedral angles, while the intermediate bisect the horizontal edges. Hence, when such bipyramids are held correctly, a face is directed towards the observer. The various axes of symmetry are located by means of the above.

**Hexagonal Bipyramid of the Second Order.**—In form, this bipyramid is similar to the preceding. It is, however, to be distinguished by its

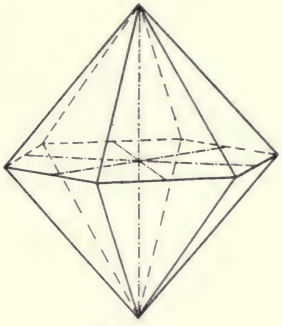


FIG. 124.

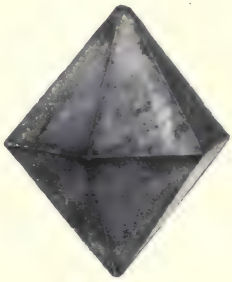


FIG. 125.

position in respect to the lateral axes. The bipyramid of the second order is so held that an edge, and not a face, is directed towards the observer. This means that the lateral axes are perpendicular to and bisect the horizontal edges as shown in Figs. 124 and 125. Figure 126 shows the cross-section including the secondary axes. From these figures

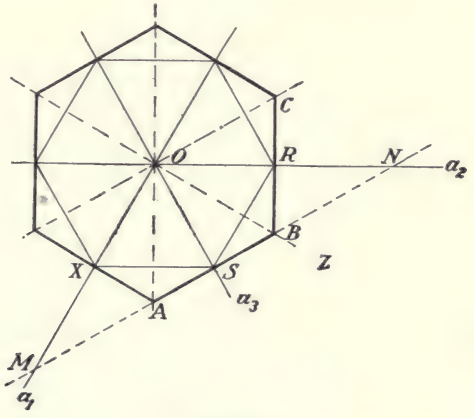



FIG. 126.

it is obvious that each face cuts one of the lateral axes at a unit distance, the other two at greater but equal distances. For example, $AB$ cuts $a_3$ at the unit distance $OS$, and $a_1$ and $a_2$ at greater but equal distances $OM$ and $ON$, respectively.

The following considerations will determine the length of $OM$ and $ON$, the intercepts on $a_1$ and $a_2$, in terms of $OS = 1$.

As already indicated, the lateral axes are perpendicular to the horizontal edges, hence $OS$ and $ON$ are perpendicular to $AB$ and $BC$, respectively. Therefore, in the right triangles $ORB$ and $NRB$, the side $RB$ is common and the angles $OBR$ and $NBR$ are equal.[1]

Therefore, $OR = RN$. But $OR = OS = 1$.

Hence, $ON = OR + RN = 2$.

In the same manner it can be shown that the intercept on $a_1$ is equal to that along $a_2$, that is, twice the unit length. The parametral ratio of the hexagonal bipyramid of the second order, therefore, is $(2a : 2a : a : mc)$, or $\{hh\bar{2}hl\}$, where $\frac{2h}{l} = m$. Fig. 126 shows the positions of the bipyramids of both orders with respect to the lateral axes, the inner outline representing that of first, the outer the one of of the second order.

**Dihexagonal Bipyramid.**—The faces of this form cut the three lateral axes at unequal distances. For example, in Fig. 127 the face represented by $dB$ cuts the $a_1$ axis at $A$, $a_2$ at $C$, and $a_3$ at $B$. Assuming the shortest of these intercepts as unity, hence, $OB = a = 1$, we at once

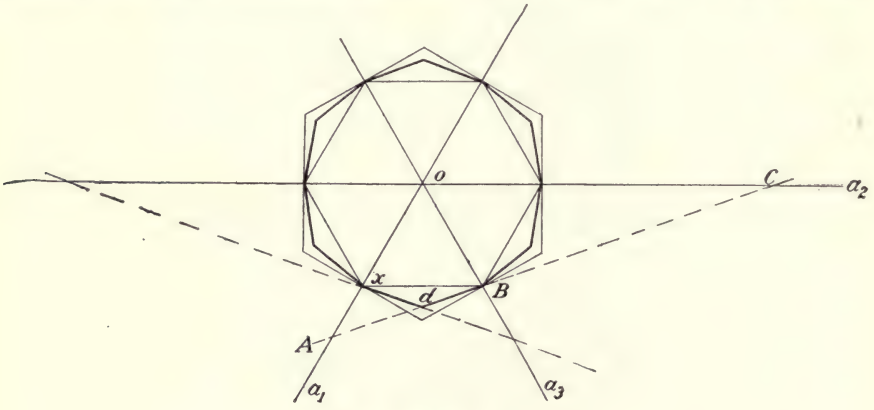



Fig. 127.

see that one of these axes is cut at a unit's distance from $O$, the other two, however, at greater distances. If we let the intercepts $OA$ and $OC$ be represented by $n(OB) = na$, and $p(OB) = pa$, respectively, the ratio will read

$$(na : pa : a : mc,)\ \{hi\bar{k}l\}.$$

In this ratio $p = \frac{n}{n-1}$. Twenty-four planes having this ratio

[1] Since angle $ABC$ equals 120°, angle $NBR$ is 60°, being the supplement of $ABC$. But the intermediate axis $OZ$ bisects the angle $ABC$, hence angle OBR is also 60°.

are possible and give rise to the form called the *dihexagonal bipyramid*, Figs. 128 and 129. In the ideal form the faces are equal, scalene triangles cutting in twenty-four polar[1]), $a$ and $b$, and twelve equal basal[2]) edges. The polar edges and angles are alternately equal. This is shown by Fig. 130, where the heavy inner outline represents the form of the first

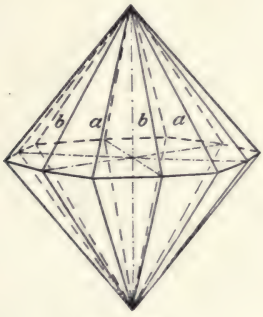



Fig. 128.

Fig. 129.

order, the outer the one of the second, and the intermediate outlines the dihexagonal type in respect to the lateral axes.

These three hexagonal bipyramids are closely related, for, if we suppose the plane represented by $AB$, Fig. 130 to be rotated about the point $B$ so that the intercept along $a_2$ increases in length, the one

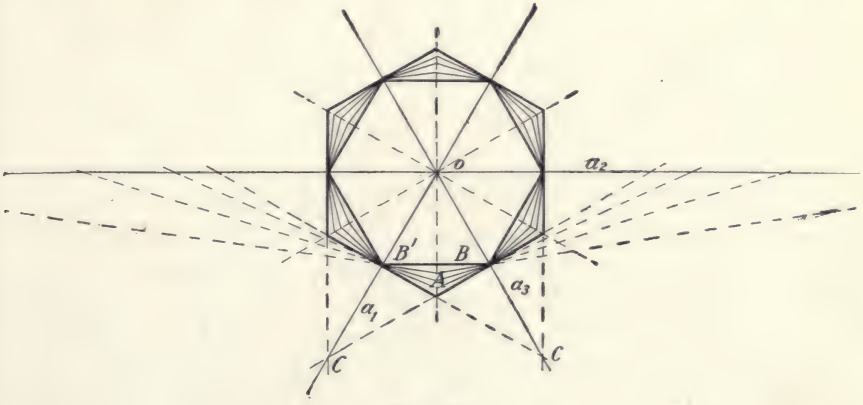



Fig. 130.

along $a_1$ decreases until it equals $oB' = oB = 1$. Then the plane is parallel to $a_2$ and the ratio for the bipyramid of the first order results. If, however, $AB$ is rotated so that the intercept along $a_2$ is decreased in length, the one along $a_1$ increases until it equals $oC = 2oB' = 2a$. When this is the case, the intercept on $a_2$ is also equal to $2a$, for then

[1] Those joining the horizontal and principal axes.

[2] These lie in the horizontal plane of symmetry.

the plane is perpendicular to $a_3$. This gives rise to the ratio of the bipyramid of the second order.

That the bipyramids of the first and second orders are the limiting forms of the dihexagonal bipyramid is also shown by the fact that $p = \frac{n}{n-1}$. For, if $n = 1$, it follows that $p = \infty$, hence, the ratio of the form of the first order. But, when $n = 2$, $p = 2$ also, therefore, the ratio for the second order results. With dihexagonal bipyramids the following holds good;

$$n > 1 < 2, \text{ and } p > 2 < \infty.$$

The dihexagonal bipyramid whose polar edges and angles are all equal is crystallographically not a possible form, because the value of $n$ would then be $\frac{1}{2}(1 + \sqrt{3}) = \sqrt{2} \cdot \sin 75° = 1.36603+$, which of course is irrational. It also follows that in those dihexagonal bipyramids, where the value of $n$ is less than $1.36603+$, for instance, $\frac{6}{5} = 1.20$, the more acute pole angles indicate the location of the lateral axes, the more obtuse that of the intermediate, and *vice versa*, when $n$ is greater than $1.36603+$, for example, $\frac{8}{5} = 1.60$. This is clearly shown by Fig. 130.

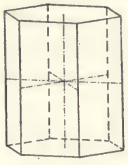


Fig. 131.

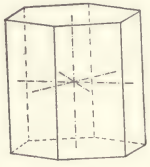


Fig. 132.

**Hexagonal Prism of the First Order.**—This form is easily derived from the bipyramid of the same order by allowing the intercept along the $c$ axis to assume its maximum value, infinity. Then the twelve planes of the bipyramid are reduced to six, each plane cutting two lateral axes at the unit distance and extending parallel to the $c$ axis. The symbols are $(a : \infty a : a : \infty c)$ or $\{10\bar{1}0\}$. This form cannot enclose space and, hence, may be termed an *open form*, page 5. It cannot occur independently and is always to be observed in combination, Fig. 131. The lateral axes join opposite edges, *i.e.*, a face is directed towards the observer when properly held.

**Hexagonal Prism of the Second Order.**—This prism bears the same relation to the preceding form that the bipyramid of the second order does to the one of the first, page 33. The symbols are $(2a : 2a : a : \infty c)$ or $\{11\bar{2}0\}$. It is, hence, an open form consisting of six faces. The lateral axes join the centers of opposite faces, hence, an edge is directed towards the observer, Fig. 132.

**Dihexagonal Prism.**—This form may be obtained from the corresponding bipyramid by increasing the value of $m$ to infinity, which gives $(na:pa:a:\infty c)$, or $\{hi\bar{k}o\}$. This prism consists of twelve faces whose alternate edges and angles are equal. This form, Fig. 133, is closely related to the corresponding bypyramid and, hence, all that has been said concerning the dihexagonal bipyramid, page 35, with respect to the location of the lateral axes and its limiting forms might be repeated here, substituting, of course, for the bipyramids of the first and second orders the corresponding prism.

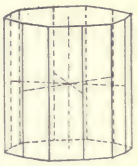


FIG. 133.

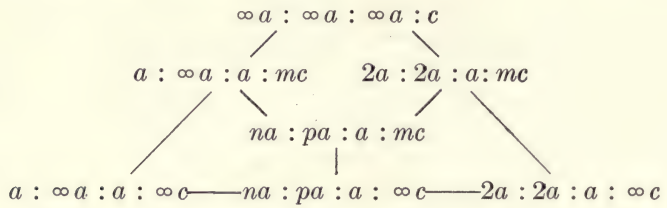
**Hexagonal Basal Pinacoid.**—The faces of this form are parallel to the horizontal plane of symmetry and possess the following symbols $(\infty a:\infty a:\infty a:\infty c)$, $\{0001\}$. It is evident from the presence of a center and horizontal axial plane of symmetry that two such planes are possible. This, like the prisms, is an open form and must always occur in combination. Figure 131 shows this form in combination with the prism of the first order.

**Summary.**—The seven forms of this class and their principal features may be summarized as follows:

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | Axial | Axial | Intermediate | |
| | 1 | 3 | 3 | 1 | 3 | 3 | 1 |

| Forms | Symbols | | Number of angles | Solid angles | | |
|---|---|---|---|---|---|---|
| | Weiss | Miller-Bravais | | Tetrahedral | Hexahedral | Dodecahedral |
| Unit Bipyramid—First order | $a:\infty a:a:c$ | $\{10\bar{1}1\}$ | 12 | 6 | 2 | — |
| Modified Bipyramids—First order | $a:\infty a:a:mc$ | $\{ho\bar{h}l\}$ | 12 | 6 | 2 | — |
| Bipyramids—Second order | $2a:2a:a:mc$ | $\{hh\bar{2}\bar{h}l\}$ | 12 | 6 | 2 | — |
| Dihexagonal Bipyramids | $na:pa:a:mc$ | $\{hi\bar{k}l\}$ | 24 | 6+6 | — | 2 |
| Prism—First order | $a:\infty a:a:\infty c$ | $\{10\bar{1}0\}$ | 6 | — | — | — |
| Prism—Second order | $2a:2a:a:\infty c$ | $\{11\bar{2}0\}$ | 6 | — | — | — |
| Dihexagonal Prisms | $na:pa:a:\infty c$ | $\{hi\bar{k}o\}$ | 12 | — | — | — |
| Basal Pinacoid | $\infty a:\infty a:\infty a:c$ | $\{0001\}$ | 2 | — | — | — |

**Relationship of Forms.**—The following diagram, similar to the one for the cubic system, page 20, expresses very clearly the relationship existing between the various forms.




**Combinations.**—The following figures illustrate some of the combinations of forms of this class.

Figure 134, $p = (a : \infty a : a : c)$, $\{10\bar{1}1\}$; $n = (2a : 2a : a : c)$, $\{11\bar{2}2\}$. Figure 135, $m = (a : \infty a : a : \infty c)$, $\{10\bar{1}0\}$; $p = (a : \infty a : a : c)$, $\{10\bar{1}1\}$.

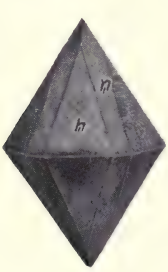



Fig. 134.

Fig. 135.

Fig. 136.

Figure 136, $m = (a : \infty a : a \infty c)$, $\{10\bar{1}0\}$; $a = (2a : 2a : a : \infty c)$, $\{11\bar{2}0\}$; $p = (a : \infty a : a : c)$, $\{10\bar{1}1\}$; $s = (2a : 2a : a : 2c)$, $\{11\bar{2}1\}$; $c = (\infty a : \infty a : \infty a : c)$, $\{0001\}$. This combination is observed on beryl ($Be_3Al_2Si_6O_{18}$).

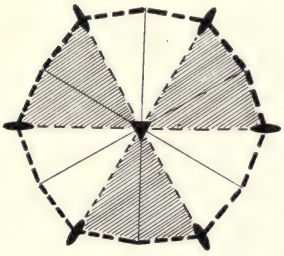


Fig. 137.

### DITRIGONAL SCALENOHEDRAL CLASS[1]

**Symmetry.**—The symmetry consists of three intermediate planes, three axes of binary and one of trigonal symmetry, and the center of symmetry. The binary axes are the lateral crystallographic axes. The principal crystallographic, or $c$, axis possesses trigonal symmetry. Figure 137 shows the distribution of these elements of symmetry. This class contains two forms which are morphologically new, rhombohedrons and scalenohedrons.

**Rhombohedrons.**—These are bounded by six rhombic faces intersecting in eight trihedral angles. The $c$ axis passes through the two equal trihedral angles which may be either larger or smaller than the other six

[1] Dana terms this class the *rhombohedral group.*

which among themselves are equal. The size of these angles depends upon the value of the ratio $a : c$.[1] This is illustrated by Figs. 138, 139 and 140. Positive (Figs. 139 and 140) and negative (Fig. 138) rhombohedrons are possible. In the positive form, the upper dodecant to the

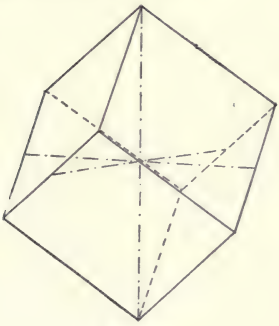


FIG. 138.

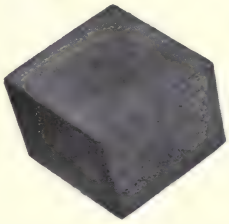


FIG. 139.

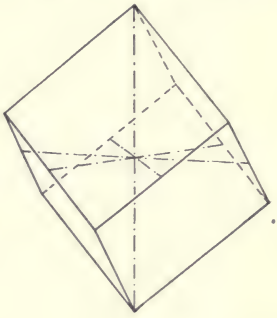


FIG. 140.

front possesses a face; in the negative an edge. The symbols are: $\pm (a : \infty a : a : mc)$, or $\{ho\bar{h}l\}$ and $\{oh\bar{h}l\}$. These ratios correspond to those of the hexagonal bipyramids of the first order, page 32.

The principal crystallographic axis passes through the two equal trihedral angles. The lateral axes bisect opposite lateral edges which form a zigzag line about the form. These axes possess trigonal and binary

[1] The cube, when held so that one of its axes of trigonal symmetry, page 17, is vertical, may be considered as a rhombohedron whose edges and angles are equal. The ratio, $a : c$, in this case would be $1 : \sqrt{1.5} = 1 : 1.2247+$. Those rhombohedrons, therefore, whose $c$ axes have a greater value than $1.2247+$ have pole angles less than

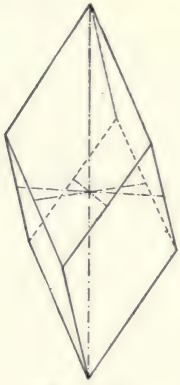


FIG. 141.

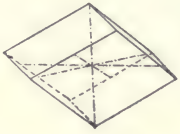


FIG. 142.

90°. When, however, the value is less than $1.2247+$, the pole angles are then greater than 90° and, hence, such rhombohedrons may be spoken of as *acute* and *obtuse*, respectively, Figs. 141 and 142.

symmetry, respectively. The intermediate planes of symmetry bisect the various faces vertically.

**Scalenohedrons.**—These forms are bounded by twelve similar scalene triangles intersecting in six obtuse and six more acute polar edges and in six zigzag lateral edges. The forms are congruent and hence may be positive, Figs. 144 and 145, or negative, Fig. 143, in character. As is the case with the rhombohedrons, obtuse and acute scalenohedrons are also possible, depending upon the value of $a : c$.

The symbols are $\pm(na : pa : a : mc)$, or $\{hi\bar{k}l\}$ and $\{ih\bar{k}l\}$. These symbols correspond to those of the dihexagonal bipyramids, page 34.

Scalenohedrons with twelve equal polar edges are crystallographically impossible as such forms would possess irrational coefficients.

The axis of trigonal symmetry passes through the two hexahedral angles, while those of binary symmetry bisect the zigzag lateral edges. The intermediate planes of symmetry pass through the polar edges.

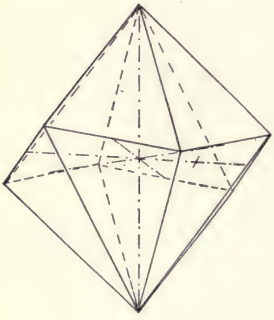


FIG. 143.

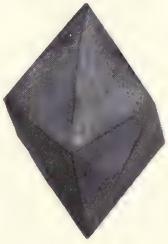


FIG. 144.

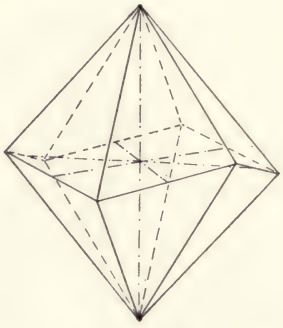


FIG. 145.

**Other Forms.**—The other forms of this class are the hexagonal bipyramids of the second order, the hexagonal prisms of the first and second orders, the dihexagonal prism, and the basal pinacoid all of which are exactly similar to those of the dihexagonal bipyramidal class.

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | ▲ Axial | ⬬ Axial | ⬬ Intermediate | |
| | 0 | 0 | 3 | 1 | 3 | 0 | 1 |

| Forms | Symbols | | Faces | Solid angles | | |
|---|---|---|---|---|---|---|
| | Weiss | Miller-Bravais | | Trihedral | Tetrahedral | Hexahedral |
| Rhombohedrons | $\pm a : \infty a : a :, mc$ | $\{ho\bar{h}l\}$ $\{oh\bar{h}l\}$ | 6 | 2 + 6 | — | — |
| Hexagonal Bipyramid Second order | $2a : 2a : a : mc$ | $\{hh\bar{2}\bar{h}l\}$ | Morphologically the same as in the dihexagonal bipyramidal class. | | | |
| Scalenohedrons | $\pm na : pa : a : mc$ | $\{hi\bar{k}l\}$ $\{ih\bar{k}l\}$ | 12 | — | 6 | 2 |
| Hexagonal Prism First order | $a : \infty a : a : \infty c$ | $\{ho\bar{h}o\}$ | Morphologically the same as in the dihexagonal bipyramidal class. | | | |
| Hexagonal Prism Second order | $2a : 2a : a : \infty c$ | $\{11\bar{2}0\}$ | | | | |
| Dihexagonal Prism | $na : pa : a : \infty c$ | $\{hi\bar{k}o\}$ | | | | |
| Basal Pinacoid | $\infty a : \infty a : \infty a : c$ | $\{0001\}$ | | | | |

**Combinations.**—Many important minerals crystallize in this class, for example, calcite, hematite, corundum, and chabazite.

FIG. 146.

FIG. 14 .

FIG. 148.

Figures 146 to 149, $m = (a : \infty a : a : \infty c)$, $\{10\bar{1}0\}$; $e = -(a : \infty a : a : \frac{1}{2}c)$, $\{01\bar{1}2\}$; $v = (\frac{3}{2}a : 3a : a : 3c)$, $\{21\bar{3}1\}$; $r\ (a : \infty a : a : c)$, $\{10\bar{1}1\}$; $f = -(a : \infty a : a : 2c)$, $\{02\bar{2}1\}$. These combinations are frequently observed on calcite ($CaCO_3$).

Figures 150 and 151, $r = (a : \infty a : a : c)$, $\{10\bar{1}1\}$; $n = (2a : 2a : a : \frac{4}{3}c)$, $\{22\bar{4}3\}$; $u = (a : \infty a : a : \frac{1}{4}c)$, $\{10\bar{1}4\}$; $c = (\infty a : \infty a : \infty a : c)$, $\{0001\}$. Hematite ($Fe_2O_3$).

Figures 152 and 153, $a = (2a : 2a : a : \infty c)$, $\{11\bar{2}0\}$; $n = (2a : 2a : a : \frac{4}{3}c)$ $\{22\bar{4}3\}$; $r = (a : \infty a : a : c)$, $\{10\bar{1}1\}$: $c = (\infty a : \infty a : \infty a : c)$, $\{0001\}$. Corundum ($Al_2O_3$).

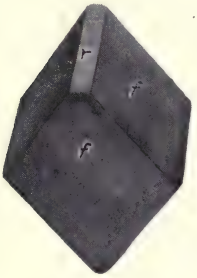



Fig. 149.

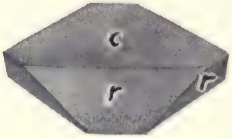



Fig. 150.

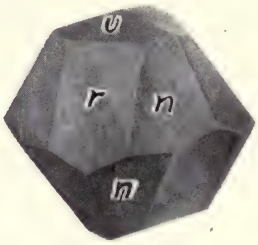



Fig. 151.

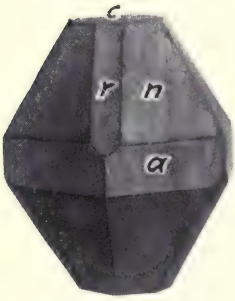



Fig. 152.

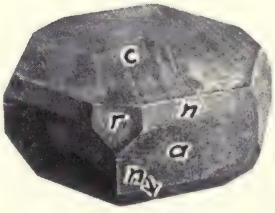



Fig. 153.

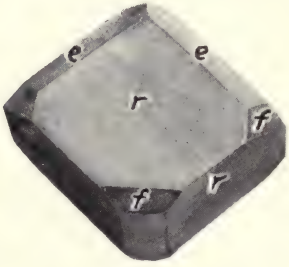



Fig. 154.

Figure 154, $r = (a : \infty a : a : c)$, $\{10\bar{1}1\}$; $e = -(a : \infty a : a : \frac{1}{2}c)$, $\{01\bar{1}2\}$; $f = -(a : \infty a : a : 2c)$, $\{02\bar{2}1\}$. Chabazite ($CaAl_2Si_6O_{16}.8H_2O$).

## HEXAGONAL BIPYRAMIDAL CLASS

**Symmetry.**—Crystals of this class possess the horizontal axial or principal plane, the hexagonal axis, and the center of symmetry. The

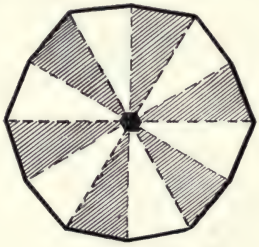


Fig. 155.

hexagonal axis is obviously the vertical or $c$ axis. Figure 155 shows the relation of these elements of symmetry.

This class contains two forms which are new: hexagonal bipyramids and prisms of the third order.

**Hexagonal Bipyramds of the Third Order.**—These bipyramids are analogous to those of the first and second orders but differ from them with respect to their orientation. Their symbols correspond to those of the dihexagonal bipyramids, page 34, namely: $\pm(na : pa : a : mc)$

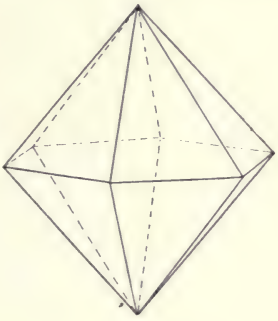


Fig. 156.

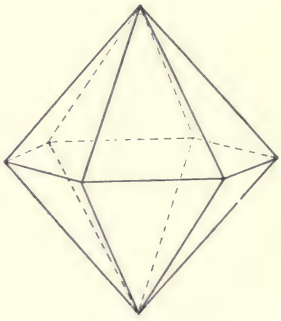


Fig. 157.

and $\{hi\bar{k}l\}$ or $\{ih\bar{k}l\}$, (Figs. 156 and 157.) They are bounded by twelve equal isosceles triangles.

The axis of hexagonal symmetry passes through the hexahedral angles. The position of the lateral crystallographic axes is shown in Figs. 158 and 159. These axes do not pass through the tetrahedral angles or the centers of the basal edges, as is the case with the forms of

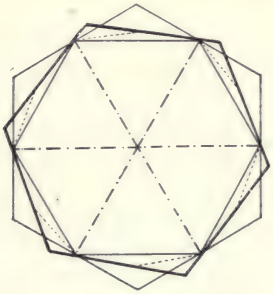


Fig. 158.

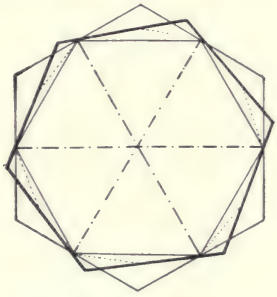


Fig. 159.

the first and second orders, respectively, but through some point between them depending upon the value of $n$. Compare Figs. 122 and 124.

**Hexagonal Prisms of the Third Order.**—These forms bear the same relation to those of the first and second order as do the hexagonal bipyramids of the third order to those of the other two orders. They consist of two forms of six planes each, designated as positive, Fig. 161, and negative, Fig. 160. Figures 158 and 159 show the relation of these

forms to the other hexagonal prisms. Their symbols correspond to those of the dihexagonal prisms, page 37, and are $\pm(na : pa : a : \infty c)$ and $\{hi\bar{k}o\}$ or $\{ih\bar{k}o\}$.

The hexagonal axis of symmetry is parallel to the vertical edges.

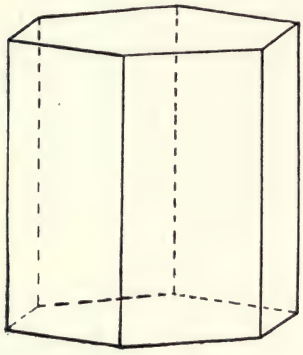


FIG. 160.

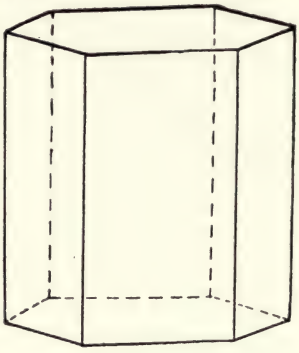


FIG. 161.

**Other Forms.**—The other forms of this class are the hexagonal bipyramids and prisms of the first and second orders and the basal pinacoid. They correspond to the analagous forms of the dihexagonal bipyramidal class.

**Summary.**—The principal features of this class have been summarized in the following table:

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | Axial ● | Axial ⬬ | Intermediate ⬬ | |
| | 1 | 0 | 0 | 1 | 0 | 0 | 1 |

| Forms | Symbols | | Faces | Angles | |
|---|---|---|---|---|---|
| | Weiss | Miller-Bravais | | Tetrahedral | Hexahedral |
| Hexagonal Bipyramids First order | $a:\infty a:a:mc$ | $\{ho\bar{h}l\}$ | Morphologically like in dihexagonal bipyramidal class. | | |
| Hexagonal Bipyramids Second order | $2a:2a:a:mc$ | $\{hh\bar{2}\bar{h}l\}$ | | | |
| Hexagonal Bipyramids Third order | $\pm na:pa:a:mc$ | $\{hi\bar{k}l\}$ $\{ih\bar{k}l\}$ | 12 | 6 | 2 |
| Hexagonal Prism First order | $a:\infty a:a:\infty c$ | $\{ho\bar{h}o\}$ | Morphologically like in dihexagonal bipyramidal class. | | |
| Hexagonal Prism Second order | $2a:2a:a:\infty c$ | $\{11\bar{2}0\}$ | | | |
| Hexagonal Prisms Third order | $\pm na:pa:a:\infty c$ | $\{hi\bar{k}o\}$ $\{ih\bar{k}o\}$ | 6 | — | — |
| Basal Pinacoid | $\infty a:\infty a:\infty a:c$ | $\{0001\}$ | Morphologically like in dihexagonal bipyramidal class. | | |

**Combinations.**—Figures 162 and 163, $m = (a:\infty a:a:\infty c)$, $\{10\bar{1}0\}$; $a = (2a:2a:a:\infty c)$, $\{11\bar{2}0\}$; $p = (a:\infty a:a:c)$, $\{10\bar{1}1\}$, $y = (a:\infty a:a:2c)$, $\{20\bar{2}1\}$; $r = (a:\infty a:a:1/2c)$, $\{10\bar{1}2\}$; $s =$

Fig. 162.

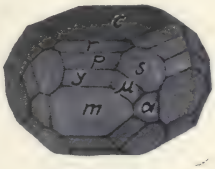



Fig. 163.

$(2a:2a:a:2c)$, $\{11\bar{2}1\}$; $\mu = (3/2a:3a:a:3c)$, $\{21\bar{3}1\}$; $c = (\infty a:\infty a:\infty a:c)$, $\{0001\}$. These combinations have been observed on apatite ($Ca_5Cl(PO_4)_3$).

## DITRIGONAL PYRAMIDAL CLASS

**Symmetry.**—There are three intermediate planes and one trigonal axis of symmetry. The axis of symmetry is the *c* axis, and has a polar development. The forms of this class, therefore, show a *hemimorphic* development, that is, the upper and lower ends of the *c* axis do not have the same type of faces. The symmetry relations are shown in Fig. 164. The following forms are morphologically different from those previously described: trigonal pyramids and prisms of the first order and ditrigonal pyramids and prisms.

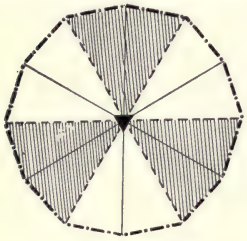
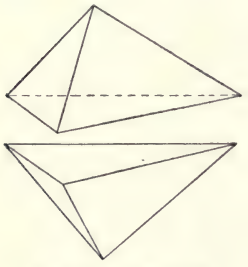


FIG. 164.

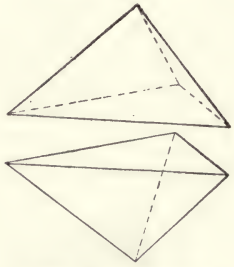
Since the *c* axis has a polar development, all forms cutting it, will occur as upper and lower forms. Thus, instead of having bipyramids, as usually is the case, we now have upper and lower pyramids.

**Trigonal Pyramids of the First Order.**—These are bounded by three equal isosceles triangles. They are open forms and may occur in four distinct positions designated as:

Positive upper, $+u(a : \infty a : a : mc)$; $\{ho\bar{h}l\}$. Fig. 167.
Positive lower, $+ l(a : \infty a : a : mc)$; $\{ho\bar{h}\bar{l}\}$. Fig. 168.
Negative upper, $-u(a : \infty a : a : mc)$; $\{oh\bar{h}l\}$. Fig. 165.
Negative lower, $-l(a : \infty a : a : mc)$; $\{oh\bar{h}\bar{l}\}$. Fig. 166.



FIGS. 165 and 166.



FIGS. 167 and 168.

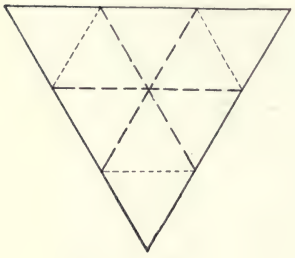


FIG. 169.

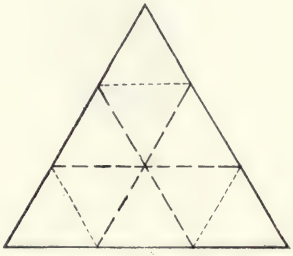


FIG. 170.

These symbols correspond to those of the hexagonal bipyramids of the first order, page 31. The axis of trigonal symmetry passes through the trihedral angle with equal edges and the intermediate planes of symmetry bisect the faces.

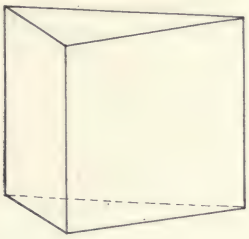


FIG. 171.

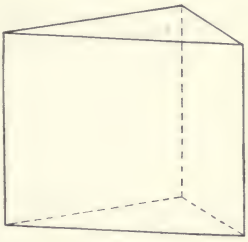


FIG. 172.

**Trigonal Prisms of the First Order.**—These prisms possess three faces and occur in positive (Fig. 172) and negative (Fig. 171) forms.

The symbols are:

$$\pm(a : \infty a : a : \infty c) \text{ or } \{ho\bar{h}o\} \text{ and } \{oh\bar{h}o\}.$$

The trigonal axis is parallel to the intersection lines of the prism faces and the intermediate planes of symmetry pass through the vertical edges and the centers of the opposite faces. Figures 169 and 170 show the positions of the various trigonal pyramids and prisms with respect to the crystallographic $a$ axes.

**Ditrigonal Pyramids.**—These pyramids are also open forms and are bounded by six scalene triangles. Four distinct positions are possible.

Their symbols are:

Positive upper, $+u(na : pa : a : mc)$, $\{hi\bar{k}l\}$. Fig. 175.
Positive lower, $+l(na : pa : a : mc)$, $\{hi\bar{k}\bar{l}\}$. Fig. 176.
Negative upper, $-u(na : pa : a : mc)$, $\{ih\bar{k}l\}$. Fig. 173.
Negative lower, $-l(na : pa : a : mc)$, $\{ih\bar{k}\bar{l}\}$. Fig. 174.

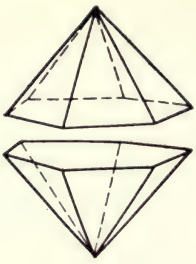
The trigonal axes pass through the hexahedral angles and the intermediate planes of symmetry include an obtuse and an acute edge.

**Ditrigonal Prisms.**—These prisms are bounded by six faces intersecting in edges which are alternately alike. Positive (Fig. 180) and negative (Fig. 179) forms are possible.

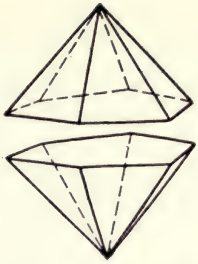
The symbols are:

$$\pm(na : pa : a : \infty c) \text{ or } \{hi\bar{k}o\} \text{ and } \{ih\bar{k}o\}.$$

The trigonal axis is parallel to the intersection lines of the prism faces and the intermediate planes of symmetry join opposite edges of unequal character. Figures 177 and 178 indicate the position of the ditrigonal pyramids and prisms with respect to the $a$ axes.



FIGS. 173 and 174.



FIGS. 175 and 176.

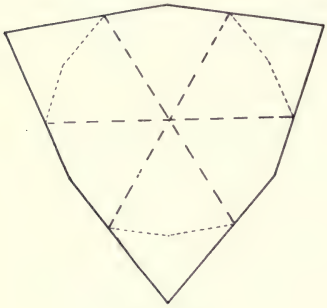


FIG. 177.

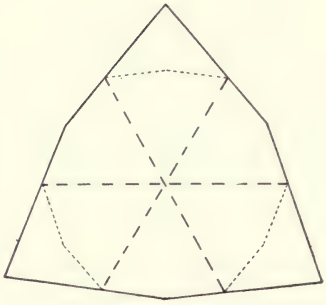


FIG. 178.

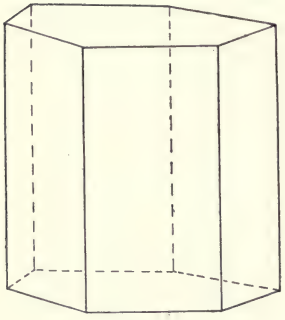


FIG. 179.

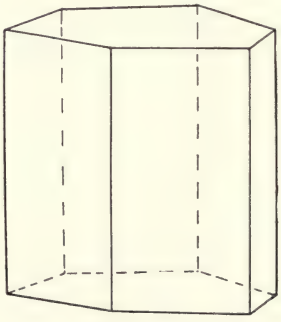


FIG. 180.

**Basal Pinacoids.**—On account of the fact that the $c$ axis has a polar development, the basal pinacoids occur with but one face (Fig. 165 to 168). We may therefore speak of an upper and a lower basal pinacoid.

The symbols are:

$$u,\ l\ (\infty a : \infty a : \infty a : c) \text{ or } \{0001\} \text{ and } \{000\bar{1}\}$$

**Hexagonal Pyramids of the Second Order.**—These forms are the upper and lower portions, respectively, of the hexagonal bipyramid of the second order described on page 33.

The symbols are:

$$u,\ l\ (2a : 2a : a : mc) \text{ or } \{hh\bar{2}\bar{h}l\} \text{ and } \{hh\bar{2}\bar{h}\bar{l}\}.$$

**Hexagonal Prisms of the Second Order.**—This form is identical morphologically with that described on page 36.

**Summary.**—The following table shows the principal features of the forms of this class:

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | ▲ Axial | ● Axial | ● Intermediate | |
| | 0 | 0 | 3 | 1 (Polar) | 0 | 0 | 0 |

| Forms | Symbols | | Number of faces | Solid angles | |
|---|---|---|---|---|---|
| | Weiss | Miller-Bravais | | Trihedral | Hexahedral |
| Trigonal Pyramids First order | $\pm u,\ \pm l,\ a:\infty a:a:mc$ | $\{ho\bar{h}l\}$ $\{ho\bar{h}\bar{l}\}$ $\{oh\bar{h}l\}$ $\{oh\bar{h}\bar{l}\}$ | 3 | 1 | — |
| Hexagonal Pyramids Second order | $u,\ l,\ 2a:2a:a:mc$ | $\{hh2\bar{h}l\}$ $\{hh2\bar{k}\bar{l}\}$ | 6 | — | 1 |
| Ditrigonal Pyramids | $\pm u,\ \pm l,\ na:pa:a:mc$ | $\{hi\bar{k}l\}$ $\{hi\bar{k}\bar{l}\}$ $\{ih\bar{k}l\}$ $\{ih\bar{k}\bar{l}\}$ | 6 | — | 1 |
| Trigonal Prisms | $\pm a:\infty a:a:\infty c$ | $\{ho\bar{h}o\}$ $\{oh\bar{h}o\}$ | 3 | — | — |
| Ditrigonal Prisms | $\pm na:pa:a:mc$ | $\{hi\bar{k}o\}$ $\{ih\bar{k}o\}$ | 6 | — | — |
| Hexagonal Prism Second order | $2a:2a:a:\infty c$ | $\{hh2\bar{h}o\}$ | Morphologically like in dihexagonal bipyramidal class. | | |
| Basal Pinacoids | $u,\ l,\ \infty a:\infty a:\infty a:c$ | $\{0001\}$ $\{000\bar{1}\}$ | 1 | — | — |

**Combinations.**—The mineral tourmaline furnishes excellent combinations of the above forms.

FIG. 181.

FIG. 182.

In the accompanying Figs. 181 and 182 $m = +(a : \infty a : a : \infty c)$, $\{10\bar{1}0\}$; $a = (2a : 2a : a : \infty c)$, $\{11\bar{2}0\}$; $u = +u(5/3a : 5/2a : a : 5c)$, $\{32\bar{5}1\}$; $o = -u(a : \infty a : a : 2c)$, $\{02\bar{2}1\}$; $o' = +l(a : \infty a : a : 2c)$ $\{20\bar{2}\bar{1}\}$; $r = -l(a : \infty a : a : c)$, $\{01\bar{1}\bar{1}\}$; $c = l(\infty a : \infty a : \infty a : c)$, $\{000\bar{1}\}$. These combinations are observed on tourmaline.

## TRIGONAL TRAPEZOHEDRAL CLASS

**Symmetry.**—The $c$ axis possesses trigonal symmetry, while the lateral or $a$ axes have binary symmetry with a polar development. The symmetry relations are given in Fig. 183.

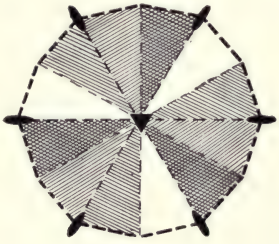


FIG. 183.

The trigonal trapezohedrons are the characterizing forms of this class.

**Rhombohedrons of the First Order.**—These are identical morphologically with those of the ditrigonal scalenohedral class.

Their symbols are:

$$\pm(a : \infty a : a : mc) \text{ or } \{ho\bar{h}l\} \text{ and } \{o\bar{h}\bar{h}l\}.$$

**Trigonal Bipyramids of the Second Order.**—These forms are bounded by six equal isosceles triangles and possess the following symbols:

$$\pm(2a : 2a : a : mc) \text{ or } \{hh\bar{2}\bar{h}l\} \text{ and } \{2h\bar{h}\bar{h}\bar{l}\}.$$

The crystallographic $a$ axes pass from a tetrahedral angle to the center of the opposite horizontal edge.

**Trigonal Trapezohedrons.**—There are four forms of this type possible. Each is bounded by six faces, which when the development is

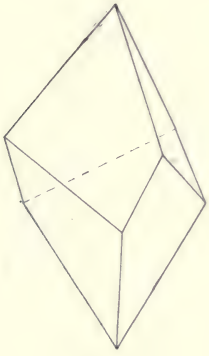


Fig. 184.

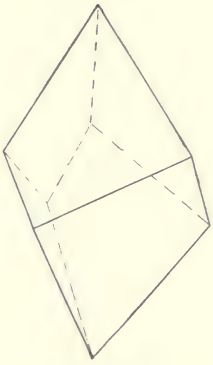


Fig. 185.

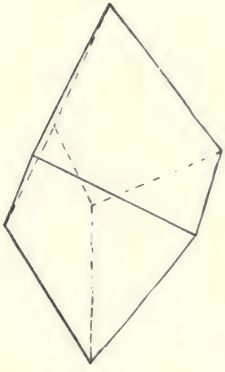


Fig. 186.

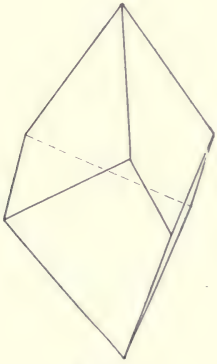


Fig. 187.

ideal, are equal trapeziums. The symbols are analogous to those of the dihexagonal bipyramids, namely,

1. Positive right, $+r(na : pa : a : mc)$, $\{hi\bar{k}l\}$, Fig. 185.
2. Positive left, $+l(na : pa : a : mc)$, $\{k\bar{i}hl\}$, Fig. 184.
3. Negative right, $-r(na : pa : a : mc)$, $\{ih\bar{k}l\}$, Fig. 187.
4. Negative left, $-l(na : pa : a : mc)$, $\{k\bar{h}il\}$, Fig. 186.

Forms 1 and 2, 3 and 4 are among themselves enantimorphous, while 1 and 3, 2 and 4 are congruent.

The polar axes of binary symmetry bisect the zigzag edges.

**Trigonal Prisms of the Second Order.**—These possess three vertical planes and have the following symbols:

$$\pm(2a : 2a : a : \infty c) \text{ or } \{hh\bar{2}\bar{h}o\} \text{ and } \{2h\bar{h}\bar{h}o\}.$$

The binary axes of symmetry pass from a vertical edge through the center of the opposite face.

**Ditrigonal Prisms.**—Two forms of this type are possible and designated as right (Fig. 189) and left (Fig. 188) ditrigonal prisms. The vertical edges are alternately alike.

The symbols are:

$$\pm(na : pa : a : \infty c) \text{ or } \{hi\bar{k}o\} \text{ and } \{ki\bar{h}o\}.$$

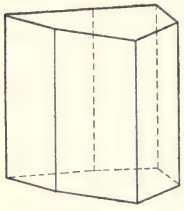


Fig. 188.

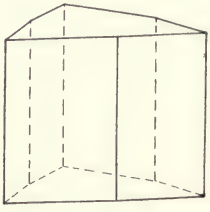


Fig. 189.

**Other Forms.** The hexagonal prism of the first order and the basal pinacoid are analogous to those described on pages 36 and 37.

**Summary.**—The important features of this class are given in the following table.

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | ▲ Axial | ⬬ Axial | ⬬ Intermediate | |
| | 0 | 0 | 0 | 1 | 3 (Polar) | 0 | 0 |

| Forms | Symbols | | Faces | Solid angles | |
|---|---|---|---|---|---|
| | Weiss | Miller-Bravais | | Trihedral | Tetrahedral |
| Rhombohedrons<br>First order | $\pm a : \infty a : a : mc$ | $\{ho\bar{h}l\}$<br>$\{oh\bar{h}l\}$ | 6 | Morphologically like those in the ditrigonal scalenohedral class. | |
| Trigonal Bipyramids<br>Second order | $\pm 2a : 2a : a : mc$ | $\{hh\bar{2}\bar{h}l\}$<br>$\{2h\bar{h}\bar{h}l\}$ | 6 | 2 | 3 |
| Trigonal Trapezohedrons | $\pm r,\ \pm l,\ na : pa : a : mc$ | $\{hi\bar{k}l\}$<br>$\{k\bar{i}\bar{h}l\}$<br>$\{ih\bar{k}l\}$<br>$\{k\bar{h}\bar{i}l\}$ | 6 | 2<br>+<br>6 | |
| Hexagonal Prism<br>First order | $a : \infty a : a : \infty c$ | $\{ho\bar{h}o\}$ | 6 | Morphologically like those in the dihexagonal bipyramidal class. | |
| Trigonal Prisms<br>Second order | $\pm 2a : 2a : a : \infty c$ | $\{hh\bar{2}\bar{h}o\}$<br>$\{2h\bar{h}\bar{h}o\}$ | 3 | | |
| Ditrigonal Prisms | $\pm na : pa : a : \infty c$ | $\{hi\bar{k}o\}$<br>$\{k\bar{i}\bar{h}o\}$ | 6 | | |
| Basal Pinacoid | $\infty a : \infty a : \infty a : c$ | $\{0001\}$ | 2 | Morphologically like those in the dihexagonal bipyramidal class. | |

**Combinations.**—Quartz, $SiO_2$, and cinnabar, HgS, furnish excellent examples of minerals crystallizing in this class.

FIG. 190.

FIG. 191.

Figures 190 and 191. $m = (a : \infty a : a : \infty c)$, $\{10\bar{1}0\}$;
$r = +(a : \infty a : a : c)$, $\{10\bar{1}1\}$; $z = -(a : \infty a : a : c)$, $\{01\bar{1}1\}$;

$s$(Fig. 191) $= +(2a : 2a : a : 2c)$, $\{11\bar{2}1\}$; $s$(Fig. 190) $= -(2a : 2a : a : 2c)$, $\{2\bar{1}\bar{1}1\}$; $x$(Fig. 191) $= +r(\frac{6}{5}a : 6a : a : 6c)$, $\{51\bar{6}1\}$; $x$(Fig. 190) $= -l(\frac{6}{5}a : 6a : a : 6c)$, $\{6\bar{1}\bar{5}1\}$. Quartz.

Figures 192 and 193. $c = (\infty a : \infty a : \infty a : c)$, $\{0001\}$; $m = (a : \infty a : a : \infty c)$, $\{10\bar{1}0\}$; $g = -(a : \infty a : a : \frac{1}{2}c)$, $\{01\bar{1}2\}$; $n = -(a : \infty a : a : 2c)$, $\{02\bar{2}1\}$; $h = -(a : \infty a : a : \frac{2}{3}c)$, $\{02\bar{2}3\}$; $r = +(a : \infty a : a : c)$, $\{10\bar{1}1\}$; $r' = -(a : \infty a : a : c)$, $\{01\bar{1}1\}$; $y = +r(\frac{3}{2}a : 3a : a : \frac{3}{7}c)$, $\{21\bar{3}7\}$; $x = +l\{\frac{8}{5}a : \frac{8}{3}a : a : \frac{8}{5}c)$, $\{83\bar{5}5\}$. Cinnabar.

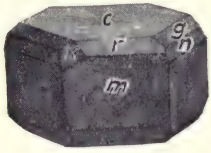



Fig. 192.

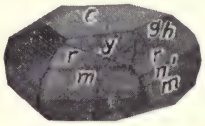



Fig. 193.

## CHAPTER IV

## TETRAGONAL SYSTEM[1]

**Crystallographic Axes.**—The tetragonal system includes all crystals which can be referred to three perpendicular axes, two of which are equal and lie in a horizontal plane. These are termed the *lateral* axes and are designated as the *a* axes. Perpendicular to the plane of the lateral axes is the *principal* or *c* axis, which may be longer or shorter than the *a* axes. The axes, which bisect the angles between the *a* axes, are the *intermediate* axes. They are designated as the *b* axes in Fig. 194.

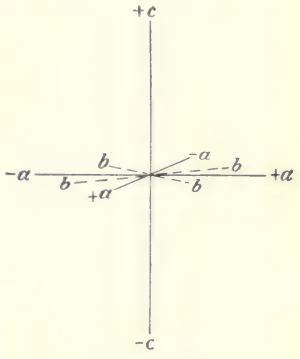


FIG. 194.

Crystals of this system are held so that the *c* axis is vertical and one of the *a* axes is directed towards the observer.

Since the lengths of the *a* and *c* axes differ, it is necessary to know the ratio existing between these axes, that is, the axial ratio, as was the case in the hexagonal system. Compare pages 6 and 30.

**Classes of Symmetry.**—This system embraces seven classes of symmetry, as follows:

1. Ditetragonal bipyramidal class.
2. Ditetragonal pyramidal class.
3. Tetragonal scalenohedral class.
4. Tetragonal bipyramidal class.
5. Tetragonal trapezohedral class.
6. Tetragonal pyramidal class.
7. Tetragonal bisphenoidal class.

Classes 1 and 3 are the most important and will be discussed in detail. No representative of class 7 has yet been observed.

### DITETRAGONAL BIPYRAMIDAL CLASS[2]

**Symmetry.** (*a*) *Planes.*—In this class there are five planes of symmetry. The plane of the lateral and intermediate axes is termed the *horizontal axial* or *principal* plane. The vertical planes including the *c*

[1] Also termed *quadratic* or *pyramidal* system.

[2] The *normal group* of Dana.

and one of the *a* axes are called the *vertical axial* planes, while those which include one of the *b* axes are termed the *intermediate* planes, Fig. 195.

The three axial planes divide space into eight equal parts, termed *octants*. The five planes, Fig. 195, divide it into sixteen equal sections. The five planes may be designated as follows:

1 Horizontal axial + 2 Vertical axial + 2 Intermediate = 5 Planes.

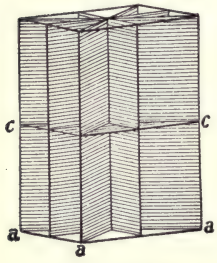



FIG. 195.

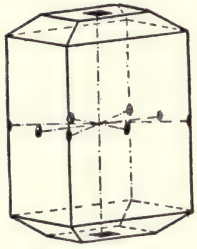


FIG. 196.

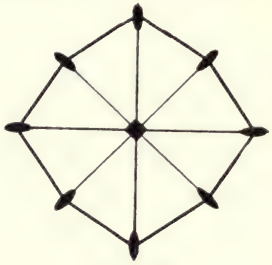


FIG. 197.

(*b*) *Axes.*—The *c* axis is an axis of *tetragonal* symmetry. The lateral and intermediate axes possess *binary* symmetry, Fig. 196. These may be written: 1 ■ + 2 ● + 2 ● = 5 axes.

(*c*) *Center.*—A center of symmetry is also present in this class. These elements of symmetry are shown in Fig. 197, which represents the projection of the most complex form upon the principal plane of symmetry.

**Tetragonal Bipyramid of the First Order.**—This form is analogous to the octahedron of the cubic system, page 16. But since the *c* axis

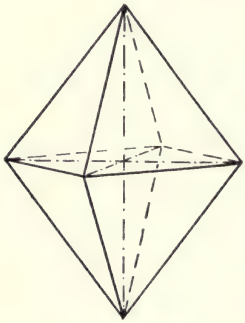


FIG. 198.

FIG. 199.

differs from the lateral axes, the ratio must be written ($a : a : c$), which would indicate the cutting of all three axes at unit distances,[1] Figs. 198 and 199. As the intercept along the *c* axis may be longer or shorter than the unit length, the general symbols would be ($a : a : mc$) or $\{hhl\}$ where *m* is some value between zero and infinity. Like the octahedron,

[1] Indicating a *unit* form, compare page 5.

this form, the *tetragonal bipyramid*,[1] is bounded by eight faces which enclose space. The faces are equal isosceles triangles when the development is ideal.

The principal crystallographic axis passes through the two tetrahedral angles of the same size, the lateral axes through the other four equal tetrahedral angles, while the intermediate axes bisect the horizontal edges.

**Tetragonal Bipyramid of the Second Order.**—The faces of this form cut the $c$ and one of the $a$ axes, but extend parallel to the other. The symbols are therefore, $(a : \infty a : mc)$ or $\{hol\}$. Eight faces are required to enclose space and the form is termed the *bipyramid of the second order*, Figs. 200 and 201.

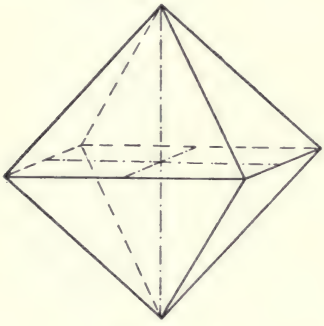


FIG. 200.

FIG. 201.

This bipyramid is very similar to the preceding, but can be readily distinguished from it on account of its position with respect to the lateral axes. In this form, the lateral axes bisect the horizontal edges and the intermediate axes pass through the four equal tetrahedral angles. This is the opposite of what was noted with the bipyramid of the first order, compare Figs. 198 and 199. Hence, the bipyramid of the first order is always held so that an edge is directed toward the observer, whereas the bipyramid of the second order presents a face. In both bipyramids the principal axis passes through the two equal tetrahedral angles.

**Ditetragonal Bipyramid.**—The faces of this bipyramid cut the two lateral axes at different distances, while the intercept along the $c$ axis may be unity or $mc$. Sixteen such faces are possible, and hence, the term *ditetragonal bipyramid* is used, Figs. 202 and 203.[2]

The symbols are:

$$(a : na : mc) \text{ or } \{hkl\}.$$

[1] The more the ratio $a : c$ approaches 1:1, the more does this form simulate the octahedron. This tendency of forms to simulate those of a higher grade of symmetry is spoken of as *pseudosymmetry*.

[2] Compare Fig. 34, page 9.

Since the polar edges[1] are alternately similar it follows that the faces are equal, similar scalene triangles. The ditetragonal bipyramid possessing equal polar edges is crystallographically an impossible form, for then the ratio $a : na : mc$ would necessitate a value for $n$ equal to the tangent of 67° 30′, namely, the irrational value 2.4142+.[2]

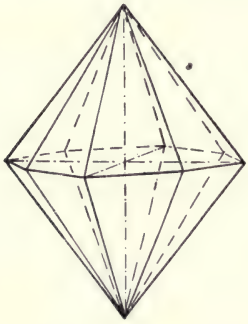


Fig. 202.

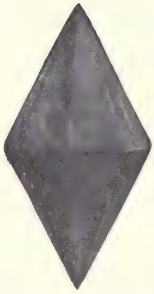


Fig. 203.

From the above it follows that when $n$ is less than 2.4142+ the ditetragonal bipyramid simulates the tetragonal bipyramid of the first order, and finally when it equals 1, it passes over into that form. On the other hand, if $n$ is greater than 2.4142+ it approaches more the bipyramid of the second order, and when it is equal to infinity passes over into that form. Hence, $n > 1 < \infty$. Figure 204 illustrates this clearly.

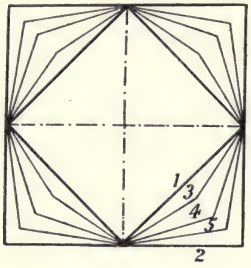



Fig. 204.

Fig. 205.

It is also to be noted, that when $n$ is less than 2.4142+ the lateral axes pass through the more acute angles, whereas, when $n$ is greater than 2.4142+ they join the more obtuse. Outline 1 represents the cross-section of the tetragonal bipyramid of the first order, 2 that of the second order, and 3, 4 and 5 ditetragonal bipyramids where $n$ equals $\frac{3}{2}$, 3, and 6, respectively.

[1] Compare footnote, page 35.

[2] See also page 36.

**Tetragonal Prism of the First Order.**—If the value of the intercept along the *c* axis in the tetragonal bipyramid of this order becomes infinity, the number of the faces of the bipyramid is reduced to four giving rise to the *tetragonal prism of the first order*, Fig. 205. This is an open form and possesses the following symbols:

$$(a : a : \infty c) \text{ or } \{110\}.$$

The lateral axes join opposite edges, hence, an edge is directed toward the observer.

**Tetragonal Prism of the Second Order.**—The same relationship exists between this form and its corresponding bipyramid as was noted on the preceding form.

The symbols are:

$$(a : \infty a : \infty c) \text{ or } \{100\}.$$

FIG. 206.

FIG. 207.

This is also an open form consisting of four faces, Fig. 206. The lateral axes join the centers of opposite faces. Hence, a face is directed toward the observer.

**Ditetragonal Prism.**—As is obvious, this form consists of eight faces possessing the following symbols:

$$(a : na : \infty c) \text{ or } \{hko\}.$$

What was indicated on page 58 concerning the polar angles and the position of the lateral axes applies here also. Figure 207 represents a ditetragonal prism.

**Basal Pinacoid.**—This form is similar to that of the hexagonal system, page 37. It is parallel to the lateral axes but cuts the *c* axis. The symbols may be written:

$$(\infty a : \infty a : c), \text{OP}, \{001\}.$$

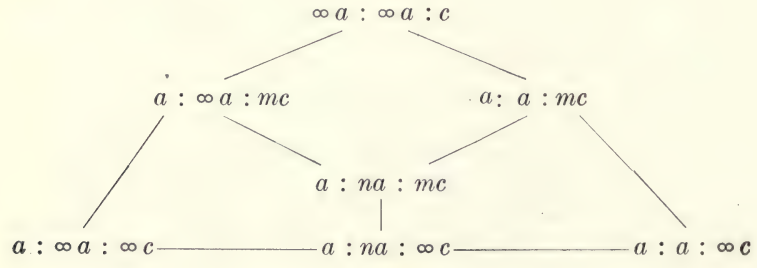
This form consists of but two faces. They are shown in combination with the three prisms in Figs. 205, 206, and 207.

**Summary.**—The seven forms in this class and the chief characteristics are given in the following table:

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | Axial | Axial | Intermediate | |
| | 1 | 2 | 2 | 1 | 2 | 2 | 1 |

| Forms | Symbols | | Faces | Solid angles | |
|---|---|---|---|---|---|
| | Weiss | Miller | | Tetrahedral | Octahedral |
| Unit Bipyramid First order | $a:a:c$ | {111} | 8 | 2+4 | — |
| Modified Bipyramids First order | $a:a:mc$ | {*hhl*} | 8 | 2+4 | — |
| Bipyramids Second order | $a:\infty a:mc$ | {*hol*} | 8 | 2+4 | — |
| Ditetragonal Bipyramids | $a:na:mc$ | {*hkl*} | 16 | 4+4 | 2 |
| Prism First order | $a:a:\infty c$ | {110} | 4 | — | — |
| Prism Second order | $a:\infty a:\infty c$ | {100} | 4 | — | — |
| Ditetragonal Prisms | $a:na:\infty c$ | {*hko*} | 8 | — | — |
| Basal Pinacoid | $\infty a:\infty a:c$ | {001} | 2 | — | — |

**Relationship of Forms.**—This is clearly expressed by the following diagram. Compare pages 20 and 38.



**Combinations.**—Some of the more common combinations are illustrated by the following figures:

Figures 208 to 211, $m = (a : a : \infty c)$, {110}; $p = (a : a : c)$, {111}; $a = (a : \infty a : \infty c)$, {100}; $x = (a : 3a : 3c)$, {311}. These combinations have been observed on zircon ($ZrSiO_4$).

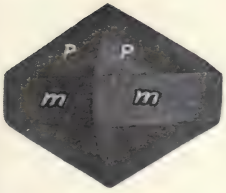



FIG. 208.

FIG. 209.

FIG. 210.

FIG. 211.

FIG. 212.

FIG. 213.

FIG. 214.

FIG. 215.

Figure 212, $m = (a : a : \infty c)$, {110}; $p = (a : a : c)$, {111}; $c = (\infty a : \infty a : c)$, {001}. Vesuvianite, $Ca_6[Al(OH,F)]\ Al_2(SiO_4)_5$.

Figure 213, $m = (a : a : \infty c)$, {110}; $a = (a : \infty a : \infty c)$, {100}; $p = (a : a : c)$, {111}; $e = (a : \infty a : c)$, {101}. Observed on rutile ($TiO_2$).

Figures 214 and 215, $a = (a : \infty a : \infty c)$, {100}; $p = (a : a : c)$, {111}; $c = (\infty a : \infty a : c)$, {001}; $y = (a : 3a : \infty c)$, {310}. Apophyllite ($H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$).

FIG. 216.

## TETRAGONAL SCALENOHEDRAL CLASS

**Symmetry.**—This class possesses two intermediate planes and three axes of binary symmetry. One of the axes of binary symmetry is the $c$ axis; the other two are the $a$ axes. This is clearly illustrated in Fig. 216. There

are two forms in this class which are morphologically new, namely, the tetragonal bisphenoids and scalenohedrons.

**Tetragonal Bisphenoids.**—These forms consist of two types, *positive* (Fig. 218) and *negative* (Fig. 217), each bounded by four equal isos-

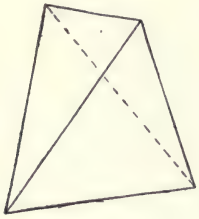


Fig. 217.

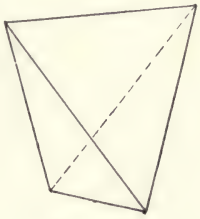


Fig. 218.

celes triangles. Their symbols are analagous to those of the tetragona bipyramids of the first order, namely:

$$\pm(a : a : mc) \text{ or } \{hhl\} \text{ and } \{h\bar{h}l\}.$$

The $a$ axes bisect the four edges of equal length, while the $c$ axis passes through the centers of the other two.

**Tetragonal Scalenohedrons.**—These consist of eight similar scalene triangles and are termed *positive* (Fig. 220) and *negative* (Fig. 219) forms. Their symbols are:

$$\pm(a : na : mc) \text{ or } \{hkl\} \text{ and } \{h\bar{k}l\}.$$

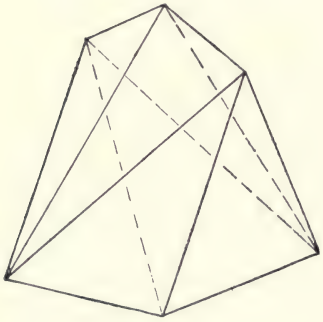


Fig. 219.

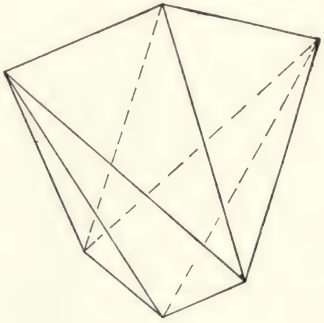


Fig. 220.

These symbols correspond to those of the ditetragonal bipyramids, page 57. The $c$ axis joins those tetrahedral angles which possess two pairs of equal edges. The $a$ axes bisect the four zigzag edges.

**Other Forms.**—The tetragonal bipyramids of the second order, the tetragonal prisms of the first and second orders, the ditetragonal prisms.

and the basal pinacoid are morphologically identical to those of the ditetragonal bipyramidal class, page 55.

**Summary.**—The characteristics of the forms of the tetragonal scalenohedral class may be tabulated as follows:

| Symmetry | Planes | | | Axes | | | Center |
|---|---|---|---|---|---|---|---|
| | Horizontal | Vertical | | Vertical | Horizontal | | |
| | Axial | Axial | Intermediate | Axial | Axial | Intermediate | |
| | 0 | 0 | 2 | 1 | 2 | 0 | 0 |

| Forms | Symbols | | Solid angles | | |
|---|---|---|---|---|---|
| | Weiss | Miller | Faces | Trihedral | Tetrahedral |
| Bisphenoids First order | $\pm a : a : mc$ | $\{hhl\}$ $\{h\bar{h}l\}$ | 4 | 4 | — |
| Bipyramid Second order | $a : \infty a : mc$ | $\{hol\}$ | Morphologically like in ditetragonal bipyramidal class | | |
| Tetragonal Scalenohedrons | $\pm a : na : mc$ | $\{hkl\}$ $\{h\bar{k}l\}$ | 8 | — | 2+4 |
| Prism—First order | $a : a : \infty c$ | $\{110\}$ | Morphologically like in ditetragonal bipyramidal class | | |
| Prism—Second order | $a : \infty a : \infty c$ | $\{100\}$ | | | |
| Ditetragonal Prisms | $a : na : \infty c$ | $\{hko\}$ | | | |
| Basal Pinacoid | $\infty a : \infty a : c$ | $\{001\}$ | | | |

**Combinations.**—The following combinations, Figs. 221 and 222,

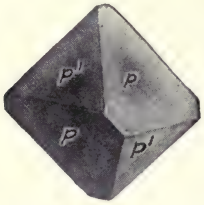



Fig. 221.

Fig. 222.

occur on chalcopyrite ($CuFeS_2$). $p = (a : a : c)$, $\{111\}$; $p' = -(a : a : c)$, $\{1\bar{1}1\}$; $\Phi = (a : a : \frac{7}{2}c)$, $\{772\}$; $x = (a : 2a : c)$, $\{212\}$.

## CHAPTER V

## ORTHORHOMBIC SYSTEM[1]

**Crystallographic Axes.**—This system includes all crystals which can be referred to three unequal and perpendicular axes Fig. 223. One axis is held vertically, which is, as heretofore, the *c* axis. Another is directed toward the observer and is the *a* axis, sometimes also called the *brachyaxis*. The third axis extends from right to left and is the *b* axis or *macroaxis*. There is no principal axis in this system, hence any axis may be chosen as the vertical or *c* axis. On this account one and the same crystal may be held in different positions by various observers, which has in some instances led to considerable confusion, for as is obvious, the nomenclature of the various forms cannot then remain con-

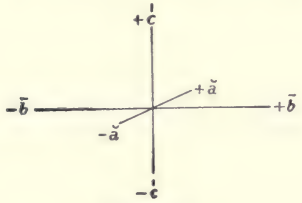



FIG. 223.

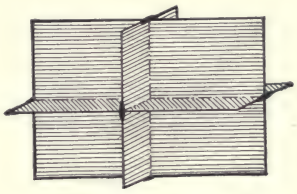


FIG. 224.

stant. In this system the axial ratio consists of two unknown values, viz: $\breve{a} : \bar{b} : \dot{c} = 0.8130 : 1 : 1.9037$, compare page 6.

**Classes of Symmetry.**—The orthorhombic system comprises three classes of symmetry, as follows:

1. Orthorhombic bipyramidal class
2. Orthorhombic pyramidal class
3. Orthorhombic bisphenoidal class

Numerous representatives of all these classes have been observed among minerals and artificial salts. The first class is, however, the most important, and will be considered in detail.

### ORTHORHOMBIC BIPYRAMIDAL CLASS[2]

**Symmetry.** (a) *Planes.*—There are three axial planes of symmetry, Fig. 224. Inasmuch as these planes are all dissimilar, they may be written:

$$1 + 1 + 1 = 3 \text{ planes.}$$

[1] Sometimes termed the *trimetric, rhombic,* or *prismatic* system.

[2] The *normal group* of Dana.

(*b*) *Axes.*—Three axes of binary symmetry are to be observed, Fig. 224. They are the crystallographic axes and indicated thus:

$$1\bullet + \bullet 1 + 1\bullet = 3 \text{ axes.}$$

(*c*) *Center.*—This element of symmetry is also present and demands parallelism of faces. Figure 225 shows the above elements of symmetry.

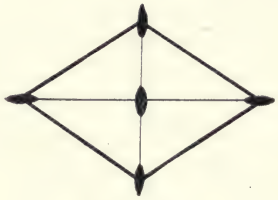


FIG. 225.

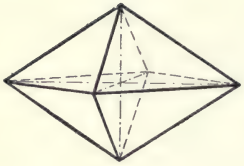


FIG. 226.

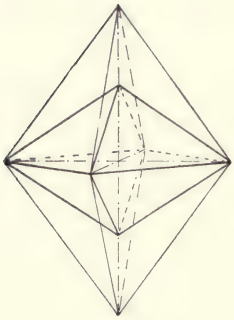


FIG. 227.

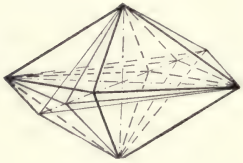


FIG. 228.

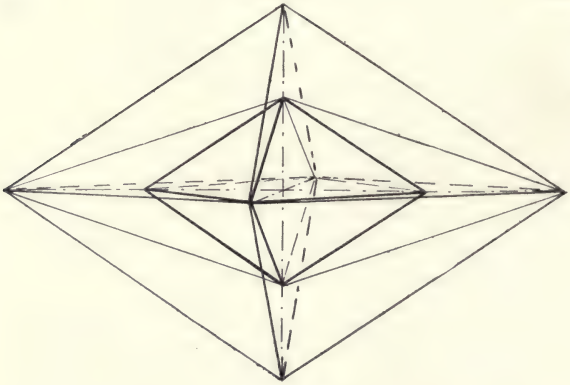


FIG. 229.

**Orthorhombic Bipyramids.**—The form whose faces possess the ratio, $(\breve{a} : \bar{b} : \dot{c})$, or $\{111\}$, is known as the *unit or fundamental orthorhombic bipyramid.* It consists of eight similar scalene triangles, Fig. 226.

The outer form, in Fig. 227, possesses the ratio $(\breve{a} : \bar{b} : m\dot{c})$ or $\{hhl\}$, $(m>0<\infty)$. In this case $m = 2$. This is a *modified orthorhombic bipyramid.*

In Fig. 228, the heavy, inner form is the unit bipramid. The lighter bipyramids intercept the $\bar{b}$ and $\dot{c}$ axes at unit distances but the $\breve{a}$ axis at distances greater than unity. Their ratios may, however, be indicated in general as,

$$(n\breve{a} : \bar{b} : m\dot{c}),\ (n>1;\ m>0<\infty)\ \text{or}\ \{hkl\}.$$

These are the *brachybipyramids*, because the intercepts along the *brachyaxis* are greater than unity.

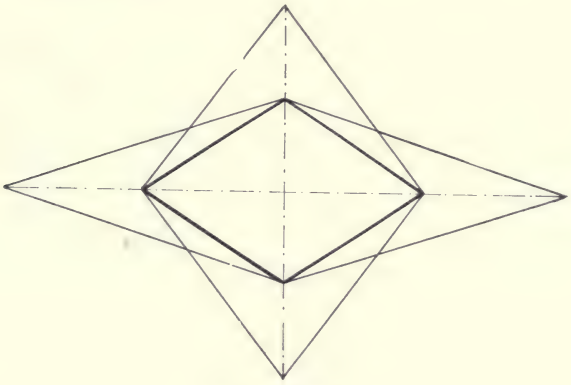


Fig. 230.

Figure 229 shows two bipyramids (outer) which cut the $\breve{a}$ axis at unity but intercept the $\bar{b}$ axis at the general distance $nb$, $(n>1)$. The ratios would, therefore, be expressed by $(\breve{a} : n\bar{b} : m\dot{c})$. Since the intercepts along the *macroaxis* are greater than unity, these are called *macrobipyramids*.

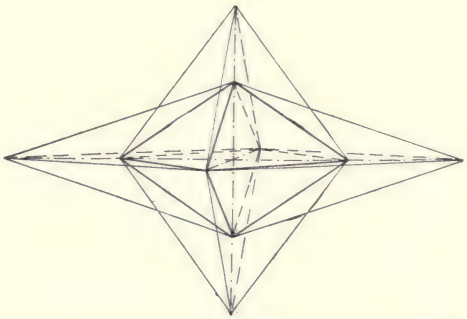


Fig. 231.

Figure 230 shows the relationship existing between the *unit*, *macro-*, and *brachybipyramids*, while Fig. 231 shows it for the *unit*, *modified*, and *macrobipyramids*.

**Prisms.**—Similarly there are three types of prisms, namely, the *unit*, *macro-*, and *brachyprisms* Each consists of four faces, cutting the $\breve{a}$ and $\bar{b}$ axes, but extending parallel to the $\dot{c}$ axis

Figures 232 and 233 represent *unit prisms* with the following symbols:

$$(\breve{a} : \bar{b} : \infty \dot{c}) \text{ or } \{110\}.$$

The *brachyprism* is shown in Fig 234. Its symbols are:

$$(n\breve{a} : \bar{b} : \infty \dot{c}) \text{ or } \{hko\}.$$

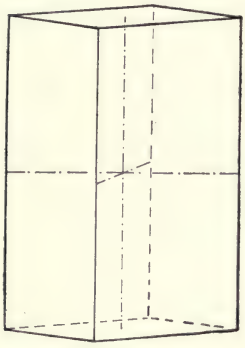


FIG. 232.

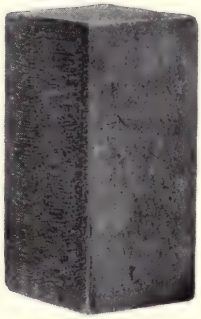


FIG. 233.

In Fig. 235, there is a unit prism surrounded by a *macroprism*, whose symbols may be written:

$$(\breve{a} : n\bar{b} : \infty \dot{c}) \text{ or } \{kho\}.$$

For the relationship existing between these three prisms compare Fig 230.

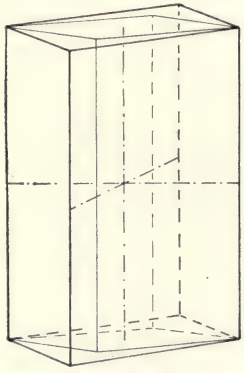


FIG. 234.

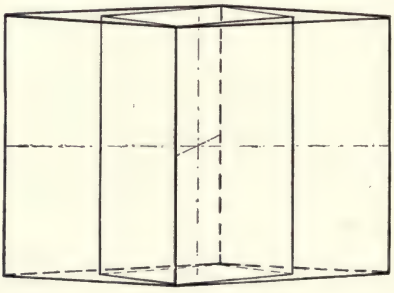


FIG 235.

**Domes.**—These are *horizontal prisms* and, hence, cut the $\dot{c}$ and one of the horizontal axes. Domes, which are parallel to the $\breve{a}$ or brachyaxis are called *brachydomes*. Their general symbols are:

$$(\infty \breve{a} : \bar{b} : m\dot{c}) \text{ or } \{ohl\}, \text{ Fig. 236.}$$

Those, which extend parallel to the macroaxis, are termed *macrodomes*, Figs. 237 and 238. Their symbols are:

$$(\breve{a} : \infty \bar{b} : m\dot{c}) \text{ or } \{hol\}.$$

As is obvious, prisms and domes are open forms and, hence, can only occur in combination with other forms.

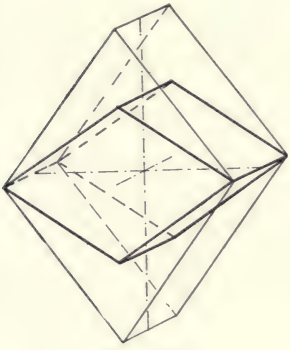


FIG. 236.

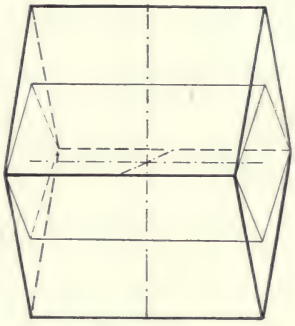


FIG. 237.

FIG. 238.

**Pinacoids.**—These cut one axis and extend parallel to the other two. There are three types, as follows:

*Basal pinacoid*, $(\infty \breve{a} : \infty \bar{b} : \dot{c})$ or $\{001\}$.
*Brachypinacoid*, $(\infty \breve{a} : \bar{b} : \infty \dot{c})$ or $\{010\}$.
*Macropinacoid*, $(\breve{a} : \infty \bar{b} : \infty \dot{c})$ or $\{100\}$.

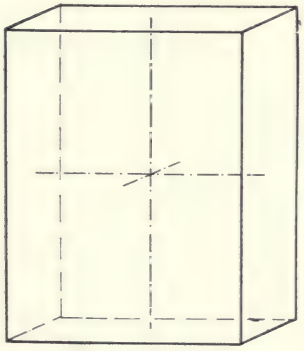


FIG. 239.

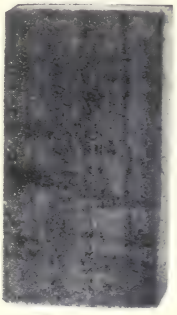


FIG. 240.

These forms consist of two faces. Figures 239 and 240 show a combination of three types of the pinacoids.

**Summary.**—The characteristics of the forms of this class are given in the following table:

| Symmetry | Planes (axial) | Axes | Center |
|---|---|---|---|
| | 1+1+1 | 1● +1● +1● | 1 |

| Forms | | Symbols: Weiss | Symbols: Miller | Faces | Tetrahedral solid angles |
|---|---|---|---|---|---|
| Orthorhombic Bipyramids | Unit | $\breve{a}:\bar{b}:\dot{c}$ | {111} | 8 | 2+2+2 |
| | Modified | $\breve{a}:\bar{b}:m\,\dot{c}$ | {*hhl*} | | |
| | Brachy | $n\breve{a}:\bar{b}:m\dot{c}$ | {*hkl*} | | |
| | Macro | $\breve{a}:n\bar{b}:m\dot{c}$ | {*khl*} | | |
| Orthorhombic Prisms | Unit | $\breve{a}:\bar{b}:\infty\,\dot{c}$ | {110} | 4 | |
| | Brachy | $n\breve{a}:\ \bar{b}:\infty\,\dot{c}$ | {*hko*} | | |
| | Macro | $\breve{a}:n\bar{b}:\infty\dot{c}$ | {*kho*} | | |
| Domes | Brachy | $\infty\breve{a}:\bar{b}:m\dot{c}$ | {*ohl*} | 4 | |
| | Macro | $\breve{a}:\infty\bar{b}:m\dot{c}$ | {*hol*} | | |
| Pinacoids | Basal | $\infty\breve{a}:\infty\bar{b}:\dot{c}$ | {001} | 2 | |
| | Brachy | $\infty\breve{a}:\bar{b}:\infty\,\dot{c}$ | {010} | | |
| | Macro | $\breve{a}:\infty\bar{b}:\infty\,c$ | {100} | | |

**Combination.**—Figures 241 and 242, $p = (a : b : c)$, {111}; $s = (a : b : \frac{1}{3}c)$, {113}; $n = (\infty a : b : c)$, {011}; $c = (\infty a : \infty b : c)$, {001}. These combinations occur on native sulphur.

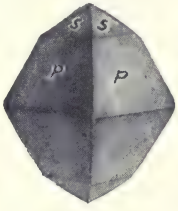



Fig. 241.

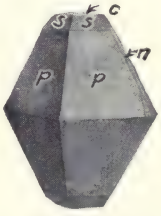



Fig. 242.

Figure 243, $m = (a : b : \infty c)$, {110}; $b = (\infty a : b : \infty c)$, {010}; $k = (\infty a : b : c)$, {011}. Aragonite ($CaCO_3$).

Figure 244, $m = (a : b : \infty c)$, {110}; $l = (2a : b : \infty c)$, {120}; $u = (a : b : c)$, {111}; $i = (a : b : 2/3c)$, {223}; $o = (a : b : 2c)$, {221};

Fig. 243.

Fig. 244.

$y = (\infty a : b : 4c)$, {041}; $c = (\infty a : \infty b : c)$, {001}. Topaz ($Al_2(F.OH)_2SiO_4$).

Figure 245, $m = (a : b : \infty c)$, {110}; $c = (\infty a : \infty b : c)$, {001}; $d = (a : \infty b : \frac{1}{2}c)$, {102}; $o = (\infty a : b : c)$, {011}. Barite ($BaSO_4$).

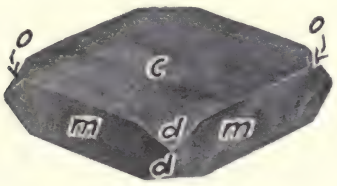



Fig. 245.

Fig. 246.

Figure 246, $m = (a : b : \infty c)$, {110}; $u = (\infty a : b : \frac{1}{4}c)$; {014}. Arsenopyrite ($FeAsS$).

## CHAPTER VI

## MONOCLINIC SYSTEM[1]

**Crystallographic Axes.**—To this system belong those crystals which can be referred to three unequal axes, two of which ($\acute{a}$ and $\acute{c}$) intersect at an oblique angle, while the third axis ($\bar{b}$) is perpendicular to these two. The oblique angle between the $\acute{a}$ and $\acute{c}$ axes is termed $\beta$. Figure 247 shows an axial cross of this system.

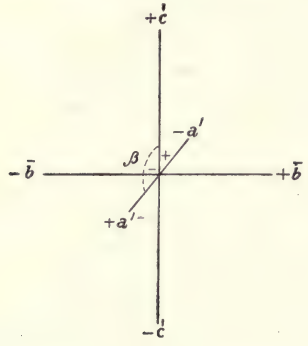



FIG. 247.

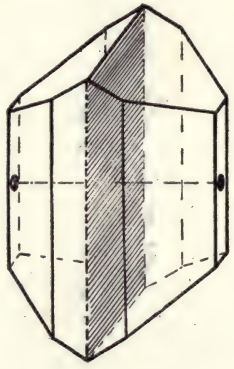


FIG. 248.

It is customary to place the $\bar{b}$ axis so as to extend from right to left. The $\acute{c}$ axis is held vertically. The $\acute{a}$ axis is then directed toward the observer. Since the $\acute{a}$ axis is inclined, it is called the *clinoaxis*. The $\bar{b}$ axis is often spoken of as the *orthoaxis*. The obtuse angle between the $\acute{a}$ and $\acute{c}$ axis is the *negative* angle $\beta$, whereas the acute angle is *positive*. Obviously, they are supplementary angles. The elements of crystallization consist of the axial ratio and the angle $\beta$, which may be either the obtuse or the acute angle. Compare page 7.

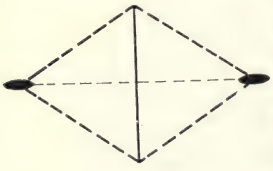


FIG. 249.

**Classes of Symmetry.**—The monoclinic system includes three classes of symmetry, as follows:

1. Prismatic class.
2. Domatic class.
3. Sphenoidal class.

The first class is the most important, and is the only one which will be considered.

[1] Also termed the clinorhombic, hemiprismatic, monoclinohedral, monosymmetric or oblique system.

## MONOCLINIC PRISMATIC CLASS[1]

**Symmetry.**—This class possesses one axial plane of symmetry ($\dot{a}$ and $\dot{c}$ axes). It is directed toward the observer. Perpendicular to this plane is an axis of binary symmetry ($\bar{b}$ axis). A center of symmetry is also present. Figure 248 shows these elements in a crystal of augite. These elements are represented diagrammatically in Fig. 249, which is a projection of a monoclinic form upon the plane of the $\dot{a}$ and $\bar{b}$ axes.

**Hemi-bipyramids.**—On account of the presence in this class of only one plane of symmetry and an axis of binary symmetry, a form with

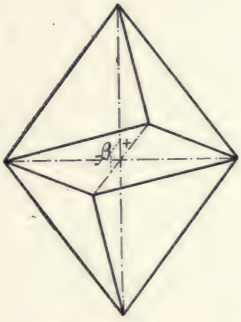



FIG. 250.

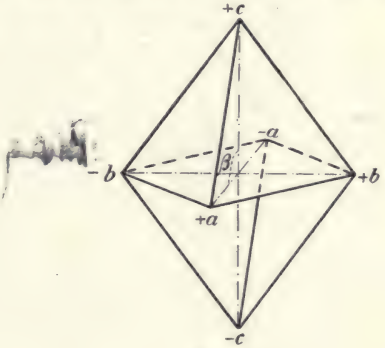



FIG. 251.

unit intercepts, that is, with the parametral ratio $\dot{a} : \bar{b} : \dot{c}$, can possess but four faces. Figure 250 shows four such faces, which enclose the positive angle $\beta$ and are said to constitute the *positive unit hemi-bipyramid.* Figure 251 shows four faces with the same ratio enclosing the negative angle $\beta$, and comprising the *negative unit hemi-bipyramid.* It is obvious that the faces of these hemi-bipyramids are dissimilar, those over the

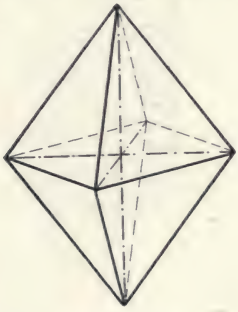


FIG. 252.

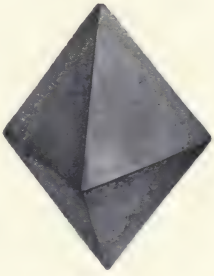


FIG. 253.

negative angle being the larger. The symbols are $\pm(a : b : c)$ or $\{111\}$ and $\{11\bar{1}\}$. Two unit hemi-bipyramids occurring simultaneously constitute the *monoclinic unit bipyramid,* Figs. 252 and 253.

[1] *Normal group* of Dana.

Since this system differs essentially from the orthorhombic in the obliquity of the $a$ axis, it follows that *modified, clino,* and *ortho* hemi-bipyramids are also possible. They possess the following general symbols:

*Modified hemi-bipyramids,*

$$\pm(\acute{a} : \bar{b} : m\dot{c}),\ m>0<\infty,\ \text{or}\ \{hh\bar{l}\}\ \text{and}\ -\{hhl\}.$$

*Clino hemi-bipyramids,*

$$\pm(n\acute{a} : \bar{b} : m\dot{c}),\ n>1;\ \text{or}\ \{hk\bar{l}\}\ \text{and}\ -\{hkl\}.$$

*Ortho hemi-bipyramids,*

$$\pm(a' : n\bar{b} : m\dot{c}),\ n>1;\ \text{or}\ \{hk\bar{l}\}\ \text{and}\ -\{hkl\}.$$

**Prisms.**—As was the case in the orthorhombic system, page 67, there are also three types of prisms possible in this system, namely, *unit, clino* and *orthoprisms.* These forms cut the $\acute{a}$ and $\bar{b}$ axes and extend parallel to the vertical axis.

The general symbols are:

*Unit prism,*

$$(\acute{a} : \bar{b} : \infty\dot{c}),\ \{110\},\ \text{Figs. 254 and 255.}$$

*Clinoprism,*

$$(n\acute{a} : \bar{b} : \infty\dot{c}),\ \{hko\};\ n>1.$$

*Orthoprism,*

$$(\acute{a} : n\bar{b} : \infty\dot{c}),\ \{kho\};\ n>1.$$

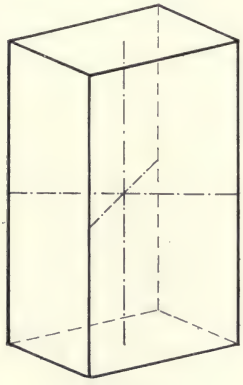


Fig. 254.

Fig. 255.

**Domes.**—In this system two types of domes are also possible, namely, those which extend parallel to the $\acute{a}$ and $\bar{b}$ axes, respectively. Those, which are parallel to $\acute{a}$, are termed *clinodomes* and consist of four faces, Fig. 256. The general symbols are:

$$\infty\acute{a} : \bar{b} : m\dot{c},\ \{ohl\}.$$

Since the $\acute{a}$ axis is inclined to the $\grave{c}$, it follows that the domes which are parallel to the $\bar{b}$ axis consist of but two faces. Figure 257 shows such faces enclosing the positive angle and are termed the *positive hemi-orthodome*, whereas in 258 the *negative hemi-orthodome* is represented. It is evident that the faces of the positive form are always the smaller. Figure 259 shows these hemidomes in combination. Their general symbols are:

*Positive hemi-orthodome,*

$(\acute{a} : \infty \bar{b} : m\grave{c})$, $\{hol\bar{l}\}$.

*Negative hemi-orthodome,*

$(\acute{a} : \infty \bar{b} : m\grave{c})$, $\{hol\}$.

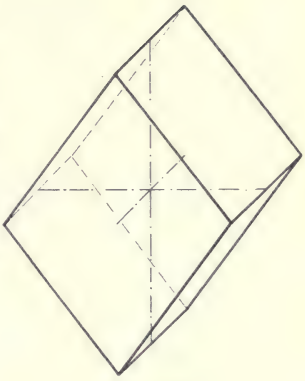


FIG. 256.

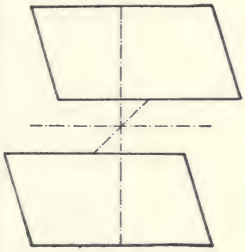


FIG. 257.

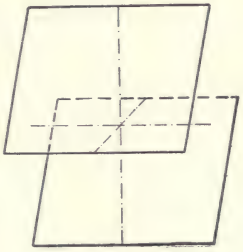


FIG. 258.

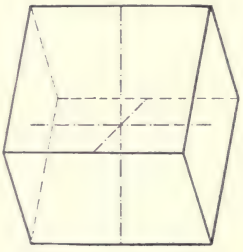


FIG. 259.

**Pinacoids.**—There are three types of pinacoids possible in the monoclinic system, namely,

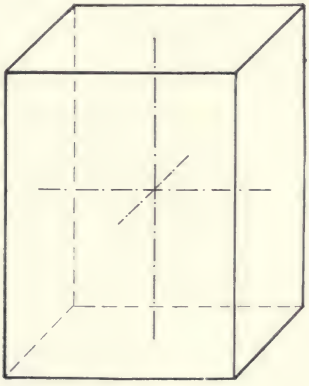


FIG. 260.

FIG. 261.

*Basal pinacoid,* $(\infty \acute{a} : \infty \bar{b} : \grave{c})$, $\{001\}$.
*Clinopinacoid,* $(\infty \acute{a} : \bar{b} : \infty \grave{c})$, $\{010\}$.
*Orthopinacoid,* $(\acute{a} : \infty \bar{b} : \infty \grave{c})$, $\{100\}$.

These are forms consisting of but two faces. Figures 260 and 261 show a combination of these pinacoids.

All forms of the monoclinic system are open forms and, hence, every crystal of this system is a combination.

A summary of the forms of this class is given as follows:

| Symmetry | Plane | Axis | Center |
|---|---|---|---|
| | 1 ($a$ and $c$ axes) | 1 ($b$ axis) | 1 |

| Forms | | Symbols | | Faces |
|---|---|---|---|---|
| | | Weiss | Miller | |
| Hemi-bipyramids | Unit | $\pm(\dot{a}:\bar{b}:\dot{c})$ | $\{11\bar{1}\}$ $\{111\}$ | 4 |
| | Modified | $\pm(\dot{a}:\bar{b}:m\dot{c})$ | $\{hh\bar{l}\}$ $\{hhl\}$ | |
| | Clino- | $\pm(n\dot{a}:\bar{b}:m\dot{c})$ | $\{hk\bar{l}\}$ $\{hkl\}$ | |
| | Ortho- | $\pm(\dot{a}:n\bar{b}:m\dot{c})$ | $\{kh\bar{l}\}$ $\{khl\}$ | |
| Prisms | Unit | $\dot{a}:\bar{b}:\infty\dot{c}$ | $\{110\}$ | 4 |
| | Clino- | $n\dot{a}:\bar{b}:\infty\dot{c}$ | $\{hko\}$ | |
| | Ortho- | $\dot{a}:n\bar{b}:\infty\dot{c}$ | $\{kho\}$ | |
| Clinodome | | $\infty\dot{a}:\bar{b}:m\dot{c}$ | $\{ohl\}$ | 4 |
| Hemi-orthodomes | Positive | $\dot{a}:\infty\bar{b}:m\dot{c}$ | $\{hc\bar{l}\}$ | 2 |
| | Negative | $\dot{a}:\infty\bar{b}:m\dot{c}$ | $\{hol\}$ | |
| Pinacoids | Basal | $\infty\dot{a}:\infty\bar{b}:\dot{c}$ | $\{001\}$ | 2 |
| | Clino- | $\infty\dot{a}:\bar{b}:\infty\dot{c}$ | $\{010\}$ | |
| | Ortho- | $\dot{a}:\infty\bar{b}:\infty\dot{c}$ | $\{100\}$ | |

**Combinations.**—The following models show some combinations of the forms of this class.

Figure 262. $m = (a : b : \infty c)$, $\{110\}$; $b = (\infty a : b : \infty c)$, $\{010\}$; $p = -(a : b : c)$, $\{111\}$. Gypsum, $CaSO_4.2H_2O$.

Fig. 262.

Fig. 263.

Fig. 264.

Fig. 265.

Figures 263, 264, and 265. $m = (a : b : \infty c)$, $\{110\}$; $b = (\infty a : b : \infty c)$, $\{010\}$; $c = (\infty a : \infty b : c)$, $\{001\}$; $y = (a : \infty b : 2c)$, $\{20\bar{1}\}$; $x = (a : \infty b : c)$, $\{10\bar{1}\}$; $o = (a : b : c)$, $\{11\bar{1}\}$; $z = (3a : b : \infty c)$, $\{130\}$. Orthoclase, $KAlSi_3O_8$.

Fig. 266.

Fig. 267.

Fig. 268.

Fig. 269.

Figures 266, 267, and 268. $m = (a : b : \infty c)$, $\{110\}$; $a = (a : \infty b : \infty c)$, $\{100\}$; $b = (\infty a : b : \infty c)$, $\{010\}$; $c = (\infty a : \infty b : c)$, $\{001\}$; $p = -(a : b : c)$, $\{111\}$; $v = -(a : b : 2c)$, $\{221\}$; $o = (a : b : 2c)$, $\{22\bar{1}\}$; $d = (a : \infty b : c)$, $\{10\bar{1}\}$; $s = (a : b : c)$, $\{11\bar{1}\}$. Pyroxene.

Figure 269. $m = (a : b : \infty c)$, $\{110\}$; $b = (\infty a : b : \infty c)$, $\{010\}$; $r = (\infty a : b : c)$, $\{011\}$. Amphibole.

## CHAPTER VII

## TRICLINIC SYSTEM[1]

**Crystallographic Axes.**—This system includes all crystals which can be referred to three unequal axes intersecting each other at oblique angles. The axes are designated as in the orthorhombic system, namely, $\breve{a}$, *brachyaxis;* $\bar{b}$, *macroaxis;* and $\dot{c}$, vertical axis. From this it follows that one axis must be held vertically, a second is directed toward the observer, and then the third is inclined from right to left or *vice versa.* Usually the brachyaxis is the shorter of the two lateral axes. Figure 270 shows an axial cross of the triclinic system. The oblique angles between the axes are indicated as follows: $\bar{b} \wedge \dot{c} = \alpha$, $\breve{a} \wedge \dot{c} = \beta$, and $\breve{a} \wedge \bar{b} = \gamma$. The elements of crystallization consist of the axial ratio and the three angles $\alpha$, $\beta$, and $\gamma$, page 6.

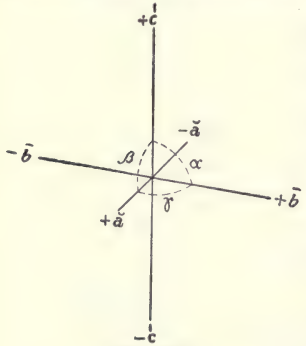


FIG. 270.

**Classes of Symmetry.**—There are but two classes of symmetry in the triclinic system, namely:

1. Pinacoidal class.
2. Asymmetric class.

The first is the important class.

### PINACOIDAL CLASS[2]

**Symmetry.**—A center of symmetry is the only element present. Hence, forms can consist of but two faces, namely, face and parallel counter-face. This is represented diagrammatically by Fig. 271, which shows a triclinic combination projected upon the plane of the $\breve{a}$ and $\bar{b}$ axes.

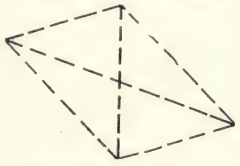


FIG. 271.

**Tetra-bipyramids.**—As already shown, triclinic forms consist of but two faces. Therefore, since the planes of the crystallographic axes divide space into four pairs of dissimilar octants, it follows that four types of pyramidal forms must result. These are spoken of as *tetrabipyramids.* There are, hence, four tetra-bipyramids, each cutting the axes at their unit lengths. The same is also true of the modified brachy- and

[1] Also termed the *anorthic, asymmetric* or *clinorhomboidal* system.

[2] *Normal group* of Dana.

macro-bipyramids. That is to say, the various bipyramids of the orthorhombic system, on account of the obliquity of the three axes, now yield four tetra-bipyramids each. They are designated as *upper right, upper left, lower right,* and *lower left* forms, depending upon which of the front octants the form encloses. The general symbols for all

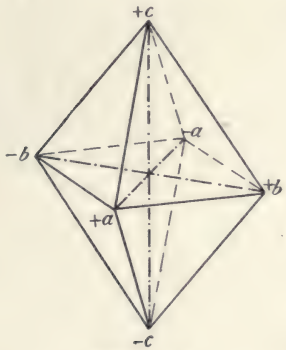



FIG. 272.

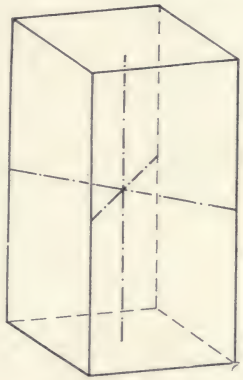


FIG. 273.

types are given in the tabulation on page 80. Figure 272 shows the four unit tetra-bipyramids in combination.

**Hemiprisms.**—Obviously the prisms are now to be designated as *right* and *left* forms. These two forms are in combination with the basal pinacoid in Fig. 273.

**Hemidomes.**—All domes now consist of but two faces. Hence, we may speak of *right* and *left hemi-brachydomes,* and *upper* and *lower hemi-macrodomes.* These forms are shown in combination with the macro- and brachypinacoids, respectively, in Figs. 274 and 275.

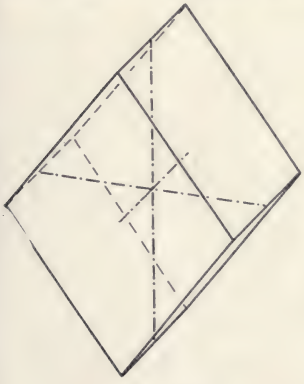


FIG. 274.

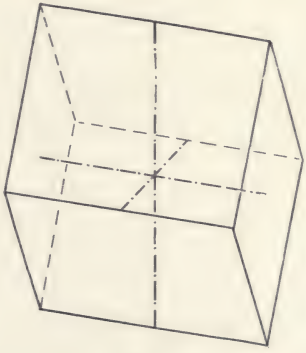


FIG. 275.

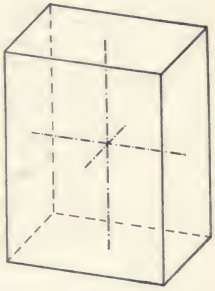


FIG. 276.

**Pinacoids.**—These forms occur with their usual number of faces and are designated, as heretofore, by the terms *basal, brachy-,* and *macro-*

*pinacoids*, depending upon the fact whether they intersect the $\dot{c}$, $\bar{b}$, or $\breve{a}$ axes. Figure 276 shows these pinacoids in combination.

**Summary.**—The various forms and symbols are given in the following table:

| Symmetry | | The only element of symmetry in this class is the *center of symmetry* | |
|---|---|---|---|
| Forms | | All forms consist of two faces | |
| | | Symbols | |
| | | Weiss | Miller |
| Tetra-bipyramids | Unit | $\breve{a}: \bar{b}: \dot{c}$ | {111} |
| | | $\breve{a}: -\bar{b}: \dot{c}$ | {1$\bar{1}$1} |
| | | $\breve{a}: \bar{b}: -\dot{c}$ | {11$\bar{1}$} |
| | | $\breve{a}: -\bar{b}: -\dot{c}$ | {1$\bar{1}\bar{1}$} |
| | Modified | $\breve{a}: \bar{b}: m\dot{c}$ | {*hhl*} |
| | | $\breve{a}: -\bar{b}: m\dot{c}$ | {*hh̄l*} |
| | | $\breve{a}: \bar{b}: -m\dot{c}$ | {*hhl̄*} |
| | | $\breve{a}: -\bar{b}: -m\dot{c}$ | {*hh̄l̄*} |
| | Brachy | $n\breve{a}: \bar{b}: m\dot{c}$ | {*hkl*} |
| | | $n\breve{a}: -\bar{b}: m\dot{c}$ | {*hk̄l*} |
| | | $n\breve{a}: \bar{b}: -m\dot{c}$ | {*hkl̄*} |
| | | $n\breve{a}: -\bar{b}: -m\dot{c}$ | {*hk̄l̄*} |
| | Macro | $\breve{a}: n\bar{b}: m\dot{c}$ | {*khl*} |
| | | $\breve{a}: -n\bar{b}: m\dot{c}$ | {*kh̄l*} |
| | | $\breve{a}: n\bar{b}: -m\dot{c}$ | {*khl̄*} |
| | | $\breve{a}: -n\bar{b}: -m\dot{c}$ | {*kh̄l̄*} |
| Hemiprisms | Unit | $\breve{a}: \bar{b}: \infty\dot{c}$ | {110} |
| | | $\breve{a}: -\bar{b}: \infty\dot{c}$ | {1$\bar{1}$0} |
| | Brachy | $n\breve{a}: \bar{b}: \infty\dot{c}$ | {*hko*} |
| | | $n\breve{a}: -b: \infty\dot{c}$ | {*hk̄o*} |
| | Macro | $\breve{a}: n\bar{b}: \infty\dot{c}$ | {*kho*} |
| | | $\breve{a}: -n\bar{b}: \infty\dot{c}$ | {*kh̄o*} |
| Hemidomes | Brachy | $\infty\breve{a}: \bar{b}: m\dot{c}$ | {*ohl*} |
| | | $\infty\breve{a}: -\bar{b}: m\dot{c}$ | {*oh̄l*} |
| | Macro | $\breve{a}: \infty\bar{b}: m\dot{c}$ | {*hol*} |
| | | $\breve{a}: \infty\bar{b}: -m\dot{c}$ | {*hol̄*} |
| Pinacoids | Basal | $\infty\breve{a}: \infty\bar{b}: \dot{c}$ | {001} |
| | Brachy | $\infty\breve{a}: \bar{b}: \infty\dot{c}$ | {010} |
| | Macro | $\breve{a}: \infty\bar{b}: \infty\dot{c}$ | {100} |

**Combinations.**—Figure 277. $x = (a : b : c), \{111\}$; $r = (a : -b : c), \{1\bar{1}1\}$; $m = (a : b : \infty c), \{110\}$; $M = (a : -b : \infty c), \{1\bar{1}0\}$; $s = (a : \infty b : 2c), \{201\}$; $a = (a : \infty b : \infty c), \{100\}$. Axinite, $HCa_2Al_2BSi_4O_{16}$.

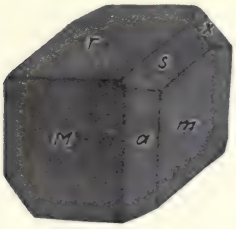



Fig. 277.

Fig. 278.

Fig. 279.

Figures 278 and 279. $m = (a : b : \infty c), \{110\}$; $M = (a : -b : \infty c), \{1\bar{1}0\}$; $b = (\infty a : b : \infty c), \{010\}$; $c = (\infty a : \infty b : c), \{001\}$; $x = (a : \infty b : -c), \{10\bar{1}\}$; $o = a : b : -c \{11\bar{1}\}$; $y = (a : \infty b : -2c), \{20\bar{1}\}$; $n = (\infty a : -b : 2c), \{0\bar{2}1\}$; $f = (3a : b : \infty c), \{130\}$; $z = (3a : -b : \infty c), \{1\bar{3}0\}$ Albite, $NaAlSi_3O_8$.

## CHAPTER VIII

## COMPOUND CRYSTALS

**General Statement.**—The crystals considered thus far have been bounded by either a single form as in the case of an octahedron (Fig. 57) or by a combination of forms (Fig. 78). They have, however, in all cases been single individuals. In many instances, crystals occur in

FIG. 280.—Aggregate of crystals, calcite. Cumberland, England.

groups and may be designated as *crystal aggregates* or *parallel groups*. A single crystal is sometimes made up of two or more individuals arranged according to some definite law. These crystals are designated as *twin crystals* or simply *twins*.

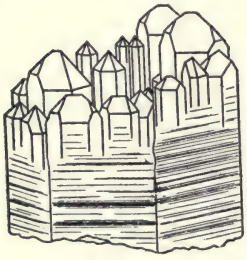


FIG. 281.

**Crystal Aggregates.**—These are groups of crystals arranged in no definite manner. They are usually singly terminated (Figs. 280 and Figs. 427, and 474, pages 204 and 222).

**Parallel Groups**—Oftentimes two or more crystals of the same substance are observed to have so intergrown that the crystallographic axes of the one individual are parallel to those of the others. Such an arrangement of crystals is termed a *parallel group*. Figures 281, 282 and 283 show such groups of quartz and calcite, respectively. Occasionally, crystals of different substances are grouped in this way.

**Twin Crystals.**—Two crystals may also intergrow so that, even though parallelism of the crystals is wanting, the growth has, nevertheless, taken

place in some definite manner. Such crystals are spoken of as *twin crystals*, or in short, *twins*. Figure 284 illustrates a twin crystal commonly observed on staurolite. In twin crystals both individuals have at least one crystal plane or a direction in common. Figure 285 shows a twinned octahedron. The plane common to both parts is termed the *composition plane*. In general, the plane to which the twin crystal is symmetrical is the *twinning plane*. In some instances, *composition* and

FIG. 282.—Parallel group of quartz crystals. Quindel, Switzerland.

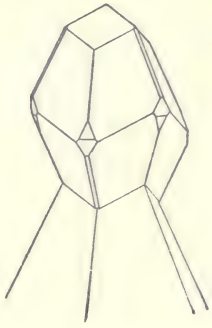


FIG. 283.

*twinning planes* coincide. Both, however, are parallel to some possible face of the crystal, which is not parallel to a plane of symmetry. The line or direction perpendicular to the twinning plane is the *twinning axis*. A *twinning law* is expressed by indicating the *twinning plane* or *axis*.

Twin crystals are commonly divided into two classes: (1) *Contact* or *Juxtaposition* twins, and (2) *Penetration* twins.[1] These are illustrated by

FIG. 284.

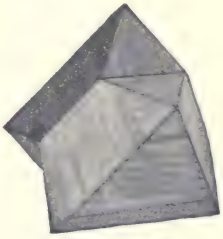


FIG. 285.

Figs. 285 and 284, respectively. Contact twins consist of two individuals so placed that if one be rotated through 180° about the twinning axis the simple crystal results. In penetration twins two individuals have interpenetrated one another. If one of the individuals be rotated

[1] Also designated as *reflection* and *rotation* twins, because they are symmetrical to a plane or an axis, respectively.

through 180° about the twinning axis both individuals will occupy the same position.

Contact and penetration twins are comparatively common in all systems. In studying twins, it must be borne in mind, as pointed out on page 12, that owing to distortion the two individuals may not be morphologically symmetrical. Re-entrant angles are commonly indicative of twinning.

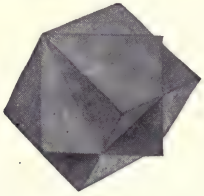


FIG. 286.

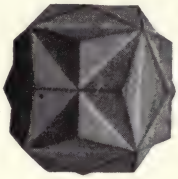


FIG. 287.

**Common Twinning Laws.**—*Cubic System.* The most common law in the cubic system is known as the *spinel* law, the twinning plane being parallel to a face of an octahedron, $(a : a : a)$ {111}. Figure 285 shows such a twin crystal of the mineral spinel. A penetration twin of fluorite is shown in Fig. 286. Here, two cubes interpenetrate according to the above law.

Figure 287 shows a penetration twin of two pyritohedrons of the mineral pyrite. These twins are often known as crystals of the *iron cross.* A plane parallel to a face of the rhombic dodecahedron, $(a : a : \infty a)$, {110}, is the twinning plane.

**Hexagonal System.**—Calcite and quartz are the only common minerals belonging to this system which furnish good examples of twinning.

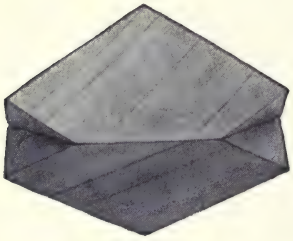


FIG. 288.

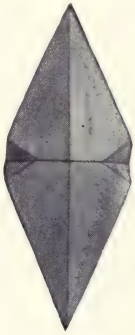


FIG. 289.

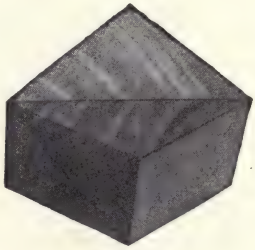


FIG. 290.

Upon calcite the basal pinacoid, $(\infty a : \infty a : \infty a : c)$, {0001}, is commonly a twinning plane. Figures 288 and 289 illustrate this law.[1] A

[1] Compare with figures 139 and 144.

plane parallel to a face of the negative rhombohedron, $-(\infty a : 2a : 2a : c)$, $\{01\bar{1}2\}$, may also be a twinning plane as illustrated by Fig. 290. These are the most common laws on calcite.

Fig. 291.

Fig. 292.

The common or Dauphine twinning law on quartz is shown in Fig. 291. Here either two right- or two left-hand crystals interpenetrate, after one has been revolved 180° about the $c$ axis as the twinning axis.

The so-called Brazilian law is common on twins of quartz, Fig. 292. Here, right and left crystals have interpenetrated so that the twin is now symmetrical to a plane parallel to a face of the prism of the second order, $(2a : 2a : a : \infty c)$, $\{11\bar{2}0\}$.

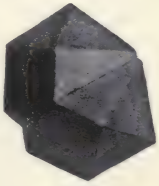


Fig. 293.

**Tetragonal System.**—Most of the twin crystals of this system are to be observed on substances crystallizing in the ditetragonal bipyramidal class. A plane parallel to a face of the unit bipyramid of the second order, $(\infty a : a : c)$ $\{011\}$, commonly acts as the twinning plane. Figure 293 shows crystals of cassiterite twinned according to this law.

**Orthorhombic System.**—The most common twins of this system belong to the bipyramidal class in which any face aside from the pinacoids may act as twinning plane. Figure 294 shows a penetration twin of staurolite, where the brachydome, $(\infty a : b : \frac{3}{2}c)$, $\{032\}$, acts as the twinning plane. Figure 295 shows the same mineral with the bipyramid, $(\frac{3}{2}a : b : \frac{3}{2}c)$, $\{232\}$, as the twinning plane. Figure 296

Fig. 294.

Fig. 295.

Fig. 296.

represents a contact twin of aragonite. Here the unit prism, $(a : b : \infty c)$, $\{110\}$, is the twinning plane.

**Monoclinic System.**—In this system, gypsum and orthoclase furnish some of the best examples. Figure 297 shows a contact twin of gypsum

FIG. 297.

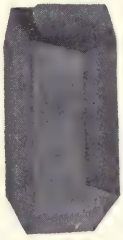


FIG. 298.

FIG. 299.

in which the orthopinacoid, $(a : \infty b : \infty c)$, $\{100\}$, is the twinning plane. Penetration twins of orthoclase are shown in Figs. 298 (left) and 299 (right). Here, the $c$ axis acts as twinning axis. This is known as the

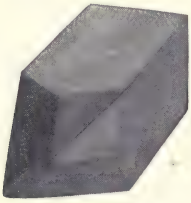


FIG. 300.

FIG. 301.

*Karlsbad law* on orthoclase. Two other twinning laws are also frequently observed on orthoclase, namely, the *Baveno* and *Mannebach* laws, where the clinodome $(\infty a : b : 2c)$, $\{021\}$ (Fig. 300), and the basal

FIG. 302.

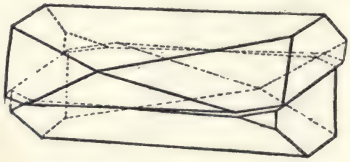


FIG. 303.

pinacoid $(\infty a : \infty b : c)$, $\{001\}$ (Fig. 301), respectively, act as the twinning planes.

**Triclinic System.**—Since there are no planes of symmetry in this system, any plane may act as the twinning plane. The mineral albite

furnishes good examples. In Fig. 302, the brachypinacoid, $(\infty a : b : \infty c)$, $\{010\}$, is the twinning plane. This is the *albite law.* Another common law is shown by Fig. 303. Here, the basal pinacoids of both individuals are parallel, the crystallographic $\bar{b}$ axis acting as the twinning axis. This is known as the *pericline law.*

**Repeated Twinning.**—In the foregoing, crystals consisting of but two individuals have been discussed. Intergrowths of three, four, five or more, individuals are termed threelings, fourlings, fivelings, and so

FIG. 304.

FIG. 305.

FIG. 306.

on. *Polysynthetic* and *cyclic* twins are the result of repeated twinning. In the polysynthetic twins the twinning planes between any two individuals are parallel. This is illustrated by Figs. 304 and 305 showing polysynthetic twins of albite and aragonite, respectively.[1] If the individuals are very thin the re-entrant angles are usually indicated by striations. Cyclic twins result when the twinning planes do not remain parallel, as for example when adjacent or opposite faces of a form act as twinning planes. This is shown by the cyclic twins of rutile, Fig. 306, in which adjacent faces of the unit bipyramid of the second order $(\infty a : a : c)$, $\{011\}$ act as twinning planes.

**Mimicry.**—As a result of repeated twinning, forms of an apparently higher grade of symmetry often result. This is especially true of those

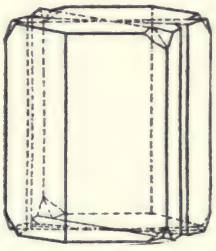


FIG. 307.

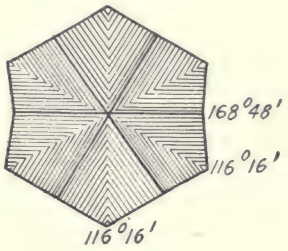



FIG. 308.

substances possessing pseudosymmetry, page 56. Figure 307 shows a trilling of the orthorhombic mineral aragonite, $CaCO_3$, which is now apparently hexagonal in its outline. In Fig. 308 the cross-section is shown. This phenomenon is called *mimicry.*

[1] Compare with figures 302 and 296.

## CHAPTER IX

## PHYSICAL PROPERTIES

Those physical properties which are easily recognized or determined, and are important in the rapid determination of minerals will be discussed in this chapter. The optical properties involving the use of the microscope will be treated later.

**Luster.**—The luster of a mineral is the appearance of its surface in reflected light, and is a property of fundamental importance in the recognition of minerals. Lusters may be divided into two large groups, namely, *metallic* and *non-metallic*. Metallic luster is indicative of metals and is exhibited by minerals which are opaque or nearly so, and quite heavy. All other lusters may be designated as non-metallic, some of the more important being:

*Vitreous.*—The luster of glass or quartz.

*Adamantine.*—The exceedingly brilliant luster of minerals with high indices of refraction, as the diamond and pyromorphite.

*Resinous.*—The luster or appearance of resin. This is well shown by sphalerite.

*Greasy.*—The appearance of an oiled surface. Example, nephelite.

*Pearly.*—This is similar to the luster of the mother of pearl. It is commonly shown by minerals with a lamellar or platy structure, and by those with pronounced cleavages. Example, talc.

*Silky.*—This luster is the result of a fibrous structure and is well shown by fibrous gypsum (satin spar) and asbestos.

*Dull.*—Not bright or shiny, good examples being chalk and kaolin. Sometimes called *earthy* luster.

The terms *splendent, shining, glistening,* and *glimmering* are sometimes used. They have reference to the intensity or quantity of light reflected. In some instances luster is not the same on all faces of a crystal. Thus, on apophyllite it is pearly on the basal pinacoid and vitreous elsewhere. When a luster is intermediate between metallic and non-metallic it is frequently called *submetallic.*

**Color.**—The color of a mineral is one of the first physical properties to be observed. Some minerals have a fairly constant color and are called *idiochromatic.* Thus, sulphur is always yellow and malachite green. In other minerals the color may vary greatly, due to the presence of pigments, inclusions, or other impurities. Such minerals are termed *allochromatic.* Good examples are calcite and quartz, both of which show

a great variety of colors. The terms used in describing the various colors need no explanation.

**Play or Change of Colors.**—Some minerals exhibit different colors as the specimen is slowly turned, or as the direction of observation is changed. This is well illustrated by labradorite and opal.

**Opalescence.**—This consists of milky or pearly reflections from the interior of the specimen, as is frequently seen in opal and moonstone. Opalescence is usually observed to best advantage on specimens with rounded and polished surfaces.

**Iridescence.**—Some minerals show a play of bright colors due to a thin coating or film on the surface of the specimen, as is often the case with limonite. In some cases it is due to cleavage cracks.

**Tarnish.**—After certain minerals have been exposed to air, the color of the exposed portions differs distinctly from that of the freshly fractured surfaces. Example, bornite.

FIG. 309.—Asterism shown by muscovite from South Burgess, Canada.*

**Asterism.**—Some minerals, like certain sapphires and rubies, exhibit a starlike light effect when viewed in reflected light. Other minerals show a similar effect in transmitted light, that is, when a source of light is viewed by holding the specimen close to the eye, for example, muscovite (Fig. 309).

**Streak.**—This is the color of the fine powder of a mineral and is frequently made use of in the determination of minerals. Although the color of minerals may vary greatly the streak is often fairly constant. The color of the streak may be determined by crushing, filing, or scratching. The usual and most satisfactory method, however, is to rub the mineral on a piece of white, unglazed porcelain, the *streak plate*. The ease or difficulty with which the streak is obtained is to some extent indicative of the hardness of a mineral.

* Figs. 309, 346 to 348, 353 to 359 and 362 to 366 are from Hauswaldt's Interferenzerscheinungen im Polarisirten Lichte.

Some minerals having the same color possess streaks which differ materially. Thus, the following three iron minerals are all black, but they can be readily distinguished by their streaks: hematite, red brown streak; limonite, yellow brown streak; magnetite, black streak.

**Hardness.**—The resistance offered by a mineral to abrasion or scratching is termed hardness. It is indicated relatively in terms of Mohs's scale, which consists of ten common minerals arranged in order of increasing hardness, as follows:

1. Talc,
2. Gypsum,
3. Calcite,
4. Fluorite,
5. Apatite,
6. Feldspar,
7. Quartz,
8. Topaz,
9. Corundum,
10. Diamond.

Beryl, 7.5 to 8 in hardness, is often substituted for topaz in the above scale.

Substances, scratched by and which in turn scratch some one member of the scale, are said to have the hardness assigned to that member. In determining the hardness of a mineral the scratch made should be as short as possible, not over ¼ inch, and care exercised to distinguish between a scratch and a chalk mark. The latter is easily removed by rubbing.

FIG. 310.—Albin Weisbach (1833–1901). Professor of mineralogy in the Saxon School of Mines, Freiberg, Germany. Pioneer in the use of physical properties for the determination of minerals.

The determination of the approximate hardness is greatly simplified by using the finger nail, copper coin, the knife blade, or a piece of window glass which possess the following values:

Finger nail, up to 2.5
Copper coin, up to 3
Knife blade, up to 5.5
Window glass, 5.5

Since the majority of the minerals are less than 6 in hardness, this simplified scale is of great convenience in determining the approximate hardness in the laboratory and field.

In the tables for the determination of minerals, which follow on pages 380 to 547, minerals have been divided into three groups based upon the hardness of calcite and feldspar, thus: (1) 1 to 3, softer than or as hard as calcite; (2) 3 to 6, harder than calcite but not harder than feldspar; (3) over 6, harder than feldspar.

**Specific Gravity.**—The specific gravity of a solid substance is its weight compared with the weight of an equal volume of water. The specific gravity of a mineral is constant, provided its composition does not vary.

Many minerals with strikingly similar physical properties often possess specific gravities which differ materially. Thus, celestite, $SrSO_4$, with a specific gravity of 3.95 can be easily distinguished from barite, $BaSO_4$, having a specific gravity of 4.5.

The specific gravity of minerals can be determined most conveniently by means of the recording Jolly balance,[1] see Fig. 311. This balance consists of a rectangular upright tube to which the inner fixed vernier and the movable doubly graduated scale are attached. This tube contains a round tube which can be moved by the large milled-head. To this second tube the outer movable vernier is fastened. A movement of

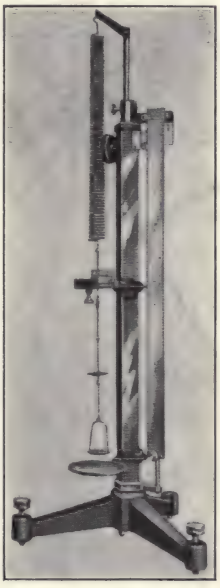


Fig. 311.

Fig. 312.

the round tube upward carries the second vernier and the graduated scale with it. Within the round tube there is a rod of adjustable length, which carries the spiral spring, index, and scale pans. With this form of balance only two readings and a simple division are necessary to determine the specific gravity.

In using the balance it is necessary that the graduated scale, the two verniers, and the index, which is attached to the spiral spring, all be at zero, the lower scale pan being immersed in water. This is accomplished by adjusting approximately by hand the length of the rod carrying the spring and then introducing the necessary correction by means of the micrometer screw shown directly below the spring in the cut, Fig. 311

[1] This balance is manufactured by Eberbach and Son Company, Ann Arbor, Michigan.

A fragment is then placed on the upper scale pan and by turning the large milled-head the round tube, graduated scale, and outer vernier are all driven upward until the index on the spring is again at zero. The fixed inner vernier W, Fig. 312 now records the elongation of the spring due to the weight of the fragment in the air. The scale is then clamped by means of the screw at the lower end of it, Fig. 311. The fragment is now transferred to the lower scale pan, immersed in water, and the round tube lowered by the large milled-head until the index again reads at zero. During this operation the outer vernier moves downward on the graduated scale and its position may now be indicated by $L$, Fig. 312. This is obviously the decrease in the elongation of spring due to the immersion of the fragment in water. The readings at $W$ and $L$ are all the data necessary for the calculation of the specific gravity. For

$$\textit{Specific gravity} = \frac{\textit{Weight in air}}{\textit{Loss of weight in water}} = \frac{W}{L}$$

It is also obvious that these readings are recorded so that they may be checked, if necessary, after the operations and calculation are completed.

By means of this balance specific gravity determinations can be readily made in about two minutes, using for the purpose a crystal or larger mineral fragment as free from impurities as possible. In order to determine the specific gravity of minerals in smaller fragments or grains it is necessary to make use of the pycnometer or specific gravity flask.

FIG. 313.

The pycnometer in its simplest form consists of a small glass flask (Fig. 313) fitted with a ground glass stopper, which is pierced length-wise by a capillary opening. The pycnometer is first weighed empty ($A$), and when filled with distilled water ($B$). The pycnometer is then emptied and after being thoroughly dried, the mineral powder, fragments, or grains are introduced and the whole weighed ($C$). The pycnometer is again filled with water and a fourth weighing made ($D$). The specific gravity can then be determined as follows:

$$\textit{Specific gravity} = \frac{C - A}{B + C - A - D}$$

Care must be exercised to remove all the air bubbles which can usually be done by boiling the water and then allowing it to cool. When this method is carefully carried out, very accurate results may be obtained. When substances are soluble in water, the determination may be made by using some liquid in which they are insoluble, for example alcohol, and then multiplying the result by the specific gravity of the liquid employed.

The chemical balance and also certain heavy liquids in connection

with the Westphal balance are sometimes used for the determination of specific gravity. These methods are very accurate but time consuming. They are generally employed in mineralogical research and but rarely by students of elementary mineralogy.

**Magnetism.**—Comparatively strong magnetism is shown by a few iron-bearing minerals, their powders or small fragments being readily attracted by a magnet. A convenient method to test the presence or absence of magnetism in a mineral, without crushing it, is to suspend a small horseshoe magnet from the finger so that it may swing freely and then bring the specimen under consideration close to the magnet. If the specimen is magnetic the magnet will be deviated from its vertical position, the amount of the deviation indicating roughly the relative strength of the magnetism. Examples, magnetite and pyrrhotite. Some minerals even act as natural magnets or lodestones and will attract considerable quantities of iron filings, tacks, and nails. Examples, certain varieties of magnetite, see Fig. 563, page 269.

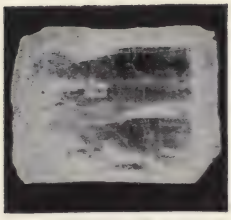


FIG. 314.—Cubical cleavage, halite. Stassfurt, Germany.

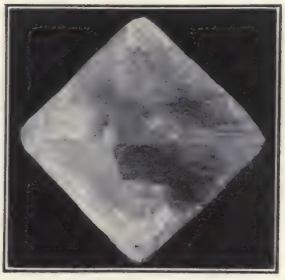


FIG. 315.—Octahedral cleavage, fluorite. Near Rosiclare, Illinois.

**Cleavage.**—Many minerals split or separate easily along definite planes. This property is called *cleavage* and is frequently very conspicuous and highly characteristic. A mineral can be cleaved by either striking it a properly directed blow with a hammer or by pressing upon it in a definite direction with the sharp edge of a knife blade. The planes along which the separation takes place are called *cleavage planes*. These planes are parallel to possible crystal faces and are so designated. Thus, cubical cleavage, that is parallel to the faces of the cube, is shown by galena and halite (Fig 314); octahedral cleavage by the diamond and fluorite (Fig. 315); rhombic dodecahedral cleavage by sphalerite; rhombohedral cleavage by calcite; prismatic cleavage by barite and celestite; basal cleavage by topaz and mica; clinopinacoidal cleavage by gypsum. The manner and ease with which cleavages are obtained are indicated by such terms as *perfect, imperfect, distinct, easy,* and so forth. Thus, calcite is said to have a perfect rhombohedral cleavage.

The cleavage of minerals, and especially of crystals, can often be recognized by the presence of cleavage cracks. In such cases it is not necessary to resort to striking the specimen a blow and, hence, shattering it somewhat, or to the use of a knife edge. As cleavage is dependent upon regularity of structure, it is only observed on crystallized substances. Amorphous substances do not possess cleavage.

*Parting* is a separation somewhat similar to cleavage and is sometimes called false cleavage. It is frequently the result of polysynthetic twinning. It may also be due to pressure applied in definite directions.

**Fracture.**—The fracture of a mineral refers to the character of the surface obtained when crystalline substances are broken in directions other than those along which cleavage or parting may take place. Minerals with no cleavage or with only a poor cleavage yield fracture surfaces very easily. As amorphous substances are devoid of cleavage, they always show fracture surfaces when shattered by a blow. The following types of fracture may be distinguished.

*Conchoidal.*—The surfaces are curved and shell-like in character. Example, quartz.

*Even.*—The fracture surfaces are flat or nearly so, that is, they are approximately even planes. Example, lithographic limestone.

*Uneven.*—The surfaces are more uneven. Example, rhodonite.

*Hackly.*—The fracture surfaces have many sharp points, and are rough and irregular. Example, copper.

*Splintery.*—The mineral breaks into splinters or fibers. Example, pectolite.

*Earthy.*—The irregular fracture characteristic of earthy substances like chalk, kaolin, and bauxite.

**Tenacity.**—Under this heading is included the behavior of minerals when an attempt is made to break, cut, hammer, crush, bend, or tear them. The most important kinds of tenacity are the following:

*Brittle.*—Easily broken or powdered, and cannot be cut into slices. Example, quartz.

*Sectile.*—Can be cut and yields shavings, which crumble when struck with a hammer, Example, gypsum.

*Malleable.*—Can be hammered out into thin sheets. Examples, gold and copper.

*Ductile.*—Can be easily drawn into wire. Example, copper and silver.

*Flexible.*—Thin layers of the mineral can be bent without breaking and they remain bent after the pressure has been removed. Example, foliated talc.

*Elastic.*—Thin layers of the mineral may be bent without breaking but they resume their positions when the pressure is removed. Example, mica.

**Transparency or Diaphaneity.**—This is the ability of a mineral to transmit light. This property can usually be recognized upon first sight, as is also the case with color and luster. Substances through which objects can be easily and distinctly seen are said to be *transparent.* Example, colorless quartz. When light passes through the substance but objects are seen only indistinctly, the mineral is *translucent.* Example, Mexican onyx. Substances are *opaque* when no light is transmitted even through thin edge or layers. Example, graphite. *Subtransparent* and *subtranslucent* indicate intermediate stages.

**Taste.**—Minerals soluble in water or the saliva generally possess a characteristic taste, which may be designated as follows:

*Acid.*—The sour taste of sulphuric acid.

*Alkaline.*—The taste of soda or potash.

*Astringent.*—This causes a contraction or puckering. Example, alum.

*Bitter.*—The taste of epsom or bitter salts.

*Cooling.*—The taste of potassium or sodium nitrate.

*Metallic.*—A very disagreeable brassy metallic taste. Example, decomposed pyrite.

*Pungent.*—A sharp and biting taste. Example, ammonium chloride.

*Saline.*—The salty taste of halite or sodium chloride.

Although the taste of a mineral is not a property of great importance, it is sometimes very useful in the rapid determination of minerals.

**Odor.**—Some minerals give off characteristic odors when breathed upon, rubbed, scratched, pounded, or heated, which are designated as follows:

*Argillaceous.*—The clay-like odor obtained by breathing upon kaolin.

*Bituminous.*—The odor produced by minerals containing bituminous or organic matter. Usually it is easily obtained by striking the specimen with a hammer. Example, asphalt.

*Fetid.*—The odor of rotten eggs, due to a liberation of hydrogen sulphide. Example, barite.

*Garlic.*—The odor of the vapors evolved when arsenical minerals are heated. Also called *alliaceous* or *arsenical* odor. Example, arsenopyrite.

*Horse-radish.*—The very disagreeable odor of decaying horse-radish obtained by heating compounds of selenium.

*Sulphurous.*—The odor of sulphur dioxide, which is liberated when sulphur or sulphides are heated or roasted. Example, pyrite.

**Feel or Touch.**—The impression one receives by handling or touching a mineral is designated as its *feel* or *touch.* The following terms are in common use.

*Cold.*—The feel of good conductors of heat. Examples, metallic minerals like copper and silver, and gems.

*Greasy or Soapy.*—The slippery feel of talc.

*Harsh or Meager.*—Rough to the touch. Example, chalk.

*Smooth.*—Without projections or irregularities. Example, meerschaum.

Some porous minerals like chalk, kaolin, and diatomaceous earth adhere readily to the tongue.

**Structure.**—Many minerals occur frequently in good crystals, as is the case with calcite and quartz. But for the most part minerals are found in masses of various types, which may be either crystalline or amorphous in character. In fact, the general structure of minerals may be classified as follows:

| | | | |
|---|---|---|---|
| 1. Crystalloids | —Crystalline Structure | Crystals | —Crystal Aggregates. Example, calcite. |
| | | Irregular Grains or Particles. | —Crystalline Aggregates. Example, marble. |
| 2. Colloids and Gels | —Amorphous Structure | —Masses | —Example, opal |

The term crystalloid refers to well developed isolated crystals or to groups or *aggregates of crystals* (Fig. 474, page 222) and also to grains or particles possessing crystal structure, but devoid of natural plane surfaces which are one of the outward expressions of crystallinity. Masses of grains or particles are called *crystalline aggregates* (Fig. 516, page 245). Colloids or gels do not crystallize and therefore yield only *amorphous masses,* which are without any definite form. Those masses which appear to the unaided eye to be amorphous, but are in reality crystalline, as revealed by the microscope, are called *cryptocrystalline.*

As was shown in Chapters II to VIII, crystals occur in a great diversity of form. These forms are very useful in the determination of minerals. There are also many types of crystalline agrgegates and amorphous masses, of which the following are the most important.

*Acicular.*—Composed of delicate and slender needle-like crystals (Fig. 666, page 325).

*Amygdaloidal.*—Almond shaped mineral masses occurring in small cavities in lavas (Fig. 415, page 197).

*Arborescent.*—Branching or tree-like aggregates of crystals (Fig. 316).

*Bladed.*—A tabular or platy structure, the individuals resembling grass or knife blades. The blades may be parallel or divergent (Fig. 583, page 282).

*Botyroidal.*—Closely united spherical masses, resembling a bunch of grapes (Fig. 529, page 253).

*Capillary.*—Composed of exceedingly slender or hair-like crystals.

*Cellular.*—Made up of pores, like a sponge. Porous.

*Clastic.*—Made up of fragments.

*Columnar.*—Composed of thick fibers or columns, often parallelly grouped (Fig. 556, page 264).

*Concentric.*—Spherical layers about a common center, similar to the layers of an onion (Fig. 477, page 223).

*Concretionary.*—Rounded or nodular masses (Fig. 481, page 224).

*Dendritic.*—Branching and fern-like structure (Fig. 317).

*Drusy.*—A rough surface due to a large number of small closely crowded crystals (Fig. 545, page 260).

*Fibrous.*—Consisting of slender fibers or filaments (Fig. 573, page 276).

*Filiform.*—Composed of thin wires, often twisted or bent (Fig. 421, page 199).

*Foliated.*—Made up of plates or leaves which are easily separated.

*Globular.*—Spherical, or nearly so.

*Granular.*—Composed of closely packed grains, which may be either coarse or fine (Fig. 603, page 289).

*Lamellar.*—Made of thin plates or layers.

*Lenticular.*—Lens-shaped.

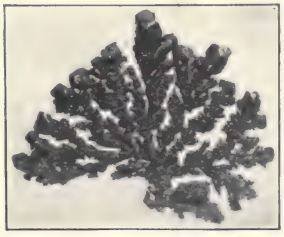


FIG. 316.—Arborescent copper. Phoenix Mine, Lake Superior District.

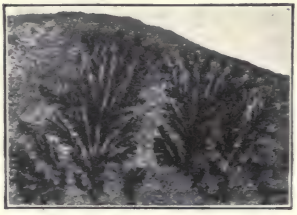


FIG. 317.—Dendritic manganite on sandstone, Malone, New York.

*Mammillary.*—Large and rounded, larger than a grape.

*Micaceous.*—Composed of very thin plates or scales, like those of mica.

*Nodular.*—Rounded masses of irregular shape (Fig. 481, page 224).

*Oolitic.*—Composed of small rounded particles the size of fish-eggs (Fig. 318).

*Phanerocrystalline.*—Crystals or coarsely crystalline (Fig. 649, page 317).

*Pisolitic.*—Composed of rounded particles, the size of peas or buckshot (Fig. 502, page 235).

*Plumose.*—Feathery structure, sometimes observed on mica.

*Reniform.*—Composed of large rounded masses resembling a kidney in shape (Fig. 495, page 230).

*Reticulated.*—Composed of fibers crossing in meshes like in a net. Fig. 319).

*Scaly.*—Composed of small thin scales or plates.

*Sheaf-like.*—Aggregates resembling a sheaf of wheat in outline (Fig. 673, page 327).

*Stalactite.*—Cylindrical or conical masses resembling icicles. (Fig. 476, page 222).

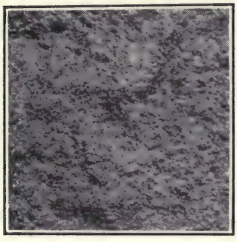


FIG. 318.—Oolitic limestone. Bedford, Indiana.

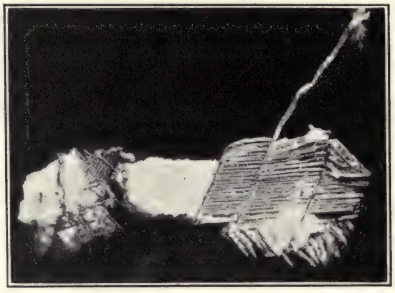


FIG. 319.—Reticulated silver. Silver King Mine, Arizona.

*Stellate.*—Radiating crystals or fibers producing star-like forms.

*Tabular.*—Composed of broad flat surfaces, tablet-like (Fig. 532, page 255).

Less frequently used terms are listed in the glossary, page 366. These are employed only when finer distinctions in structure are made.

## CHAPTER X

## THE POLARIZING MICROSCOPE

**Optical Methods.**—During recent years great advances have been made in perfecting simple methods by which certain optical constants of solids may be easily and rapidly determined. Many of these methods involve the use of the mineralogical or polarizing microscope, which differs materially from the microscope ordinarily used by biologists, pathologists, and other scientists, in that it is equipped with a rotating stage, and various devices permitting the study of objects in polarized light. In fact, in determining solids by optical methods polarized light is indispensible. It will therefore be necessary to review briefly some of the essential properties of light.

**Reflection of Light.**—It is well known that when a ray of light falls upon a polished surface, such as a mirror, it is reflected according to the

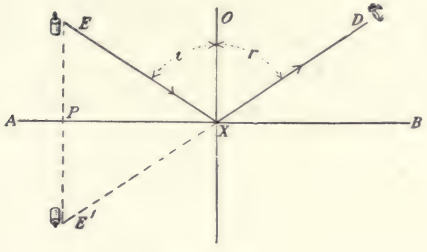



FIG. 320.

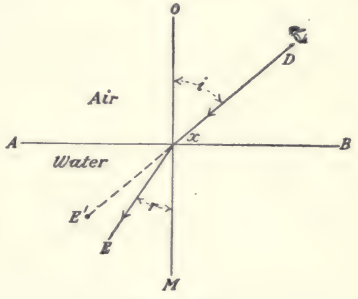



FIG. 321.

law of reflection, which states that: *the angle of incidence is equal to the angle of reflection, and the incidence and reflected rays lie in the same plane.* That is, in Fig. 320, the ray of light $EX$, from the candle at $E$, impinges upon the polished surface $AB$ at $X$ with the angle of incidence $EXO$ or $i$, and is reflected to the eye at $D$, the angle of reflection being $DXO$ or $r$. The angles $i$ and $r$ are equal. To the eye the object appears at $E'$. The line $EE'$ is perpendicular to $AB$ and the distances $EP$ and $PE'$ are equal.

**Refraction of Light—Single Refraction.**—When light passes obliquely from one medium into another, for example, from air into water, the path of the ray is not straight but bent. That is, the ray is refracted. We know this from the appearance of a rod or pencil placed in an inclined position in a glass or beaker of water. The phenomenon of refraction is clearly shown by Fig. 321. The ray $Dx$ in air impinges at $x$ upon

the surface $AB$ and in passing into the water is bent or refracted toward the normal $OM$, because the velocity of light is less in water than in air. If the angle of incidence $DxO$ be represented by $i$ and the angle of refraction $MxE$ by $r$, then the law of refraction may be stated as follows: *the ratios between the velocities of light V and V′ in the two media, and the sines of the angles of incidence and refraction, are equal and constant for the media concerned,* thus, in the case of air and water,

$$n \text{ (Index of Refraction)} = \frac{V(\text{air})}{V'(\text{water})} = \frac{\sin i}{\sin r} = 1.333.$$

The constant $n$ is called the index of refraction, the velocity of light in air being taken as unity. Thus, the index of refraction of water in terms of air is 1.3333, of the garnet 1.75, and of the diamond 2.42. It is evident that the velocity of light in a given substance is proportional to the reciprocal of its index of refraction. Hence, the larger the index, the slower the velocity, and vice versa.

In determining these values white light should not be used, for when white light passes through a prism it is resolved into its component colors—a spectrum is produced. Of these component colors, red light is refracted least and violet most. That is, the velocity of light is greatest from the red end of the spectrum, and least from the violet end. Indices of refraction must therefore be determined for a definite type of monochromatic light, commonly expressed in wave lengths, $\mu\mu$. Thus, the indices of the diamond may be given as follows:

| | | |
|---|---|---|
| $n_{\text{red}}$ | $687\mu\mu$ | $= 2.407$ |
| $n_{\text{yellow}}$ | 589 | $= 2.417$ |
| $n_{\text{green}}$ | 527 | $= 2.427$ |
| $n_{\text{violet}}$ | 397 | $= 2.465$ |

The indices of refraction for a certain variety glass are $n_{\text{red}} = 1.524$ and $n_{\text{violet}} = 1.545$.

As sources of monochromatic light, the mineralogist commonly uses non-luminous gas flames colored by some volatile salt of the following elements:

| | |
|---|---|
| Lithium, red | $670\mu\mu$ |
| Sodium, yellow | 589 |
| Thallium, green | 535 |

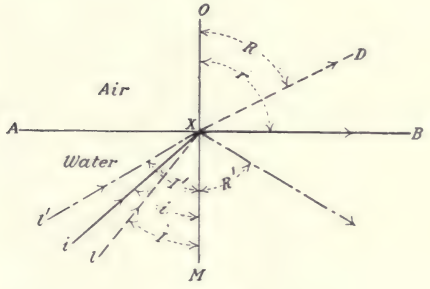
**Dispersion.**—The above examples are sufficient to show that the indices of refraction for a given substance vary considerably for the two extremes of the spectrum. This difference in velocity is called dispersion, and in the case of the diamond it is unusually high ($2.465 - 2.407 = 0.058$). The difference in the indices between opposite ends of the spectrum

indicates the strength of the dispersion. The dispersion of glass is much lower (1.545 − 1.524 = 0.021).

**Total Reflection and Critical Angle.**—When light passes from a denser into a rarer medium, for example from water into air, the refracted ray is bent away from the normal, Fig. 322. That is, the angle of incidence $I$ is now smaller than the angle of refraction $R$. It is therefore obvious that for a definite angle of incidence, $i$, the angle of refraction $r$ may equal 90°. This angle $i$ is called the *critical* angle, for when the angle of incidence exceeds $i$ in value, as for example $I'$, the ray is totally reflected; that is, it does not enter the second medium, but is reflected back into the first, so that angle $I'$ equals angle $R'$. The value of the critical angle may be expressed as

$$\sin i = \frac{1}{n}$$

where $n$ is the usual index of refraction and $i$ the angle of the incident ray in the denser medium. Hence, it follows that substances with high indices of refraction have smaller critical angles than those with low




Fig, 322.

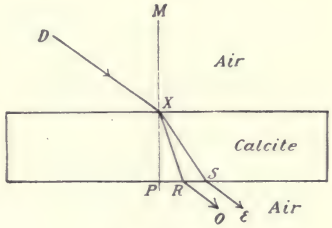



Fig. 323.

indices. The critical angle of the diamond ($n$ = 2.42) in terms of air is only 24°26′, while that of water ($n$ = 1.333) is 48°36′. The phenomenon of total reflection is of great importance in crystal optics.

**Double Refraction.**—When an oblique ray of light passes through many solids it is not only refracted but also resolved into two rays, which travel with different velocities. This phenomenon is designated as double refraction, and is characteristic of all crystallized substances other than those of the cubic system. Single refraction has been discussed on page 99.

Double refraction is illustrated in Fig. 323. The ray $DX$ is represented as impinging upon a section of the mineral calcite, $CaCO_3$. $DX$ is resolved into two rays, $o$ and $e$, of which $o$ is the slower ray and is refracted more than the faster ray $e$. The velocity of the $o$ ray is the same for all directions in the crystal and is called the *ordinary ray*. The other

ray, *e*, is termed the *extraordinary ray*. Its velocity varies with direction. In the case of calcite, illustrated in figure 323, the ordinary ray is slower than the extraordinary ray, but in other substances the conditions may be reversed; for example, zircon.

**Optical Groups.**—Substances showing single refraction are called *singly refractive* or *isotropic*, while those with double refraction are designated as *doubly refractive* or *anisotropic*. In isotropic substances the velocity of light of a given wave length does not vary with direction. There is, hence, but one index of refraction for such substances. Amorphous substances and crystals of the cubic system are isotropic. Examples: diamond (cubic), $n_y = 2.42$; garnet (cubic) $n_y = 1.75$; opal (amorphous), $n_y = 1.45$.

Anisotropic substances are subdivided into two groups, depending upon whether they possess one or two isotropic directions. These isotropic directions are called *optic axes*. Those with one isotropic direction possess two principal indices of refraction, *o* and *e*, and include crystals of the hexagonal and tetragonal systems. Examples: calcite (hexagonal), $o = 1.65$, $e = 1.48$; zircon (tetragonal) $o = 1.924$, $e = 1.968$. These substances have one optic axis and are also called *uniaxial*. The direction of the optic axis is that of *c* crystallographic axis. If the index *o* is greater than *e*, the crystal is said to be optically *negative*, and optically *positive* when *e* has the larger value. Compare the values above for calcite and zircon. The difference between the indices of the ordinary and extraordinary rays gives the strength of *double refraction* or *birefringence*. Thus for calcite it is (*o*) 1.65 − (*e*) 1.48 = 0.17; for quartz it is (*e*) 1.553 − (*o*) 1.544 = 0.009. The birefringence is characterized as strong or weak, depending upon the values obtained.

Those anisotropic crystals which possess two isotropic directions, or optic axes, are called *biaxial*. They include all crystals belonging to the orthorhombic, monoclinic, and triclinic systems. In these crystals there are three principal optical directions at right angles to each other, parallel to which light is propagated with velocities indicated by the three indices, $\alpha$, $\beta$, $\gamma$. Examples: topaz (orthorhombic), $\alpha = 1.607$, $\beta = 1.610$, $\gamma = 1.618$; epidote (monoclinic), $\alpha = 1.730$, $\beta = 1.754$ $\gamma = 1.768$; axinite (triclinic) $\alpha = 1.672$, $\beta = 1.678$, $\gamma = 1.681$. When $\beta$ approaches in value $\alpha$ more than it does $\gamma$, as in the case of topaz, the substance is optically positive. In optically negative crystals the value of $\beta$ lies nearer to $\gamma$, as is shown by the indices of epidote and axinite. The *double refraction* or *birefringence* of biaxial crystals is indicated by $\gamma$-$\alpha$; thus, for topaz it is 1.618 − 1.1607 = 0.011.

These optical properties may be summarized as follows:

| | | | |
|---|---|---|---|
| Singly refractive or Isotropic | Amorphous Substances and Cubic Crystals | | One index of refraction, $n$. |
| Doubly refractive or Anisotropic | Hexagonal, Tetragonal | Uniaxial | Two indices of refraction, $o$ and $e$. Positive $o<e$ Negative $e<o$ |
| | Orthorhombic, Monoclinic, Triclinic crystals | Biaxial | Three indices of refraction, $\alpha$, $\beta$, $\gamma$. Positive, $\alpha\beta$, $\gamma$ Negative $\alpha$, $\beta\gamma$ |

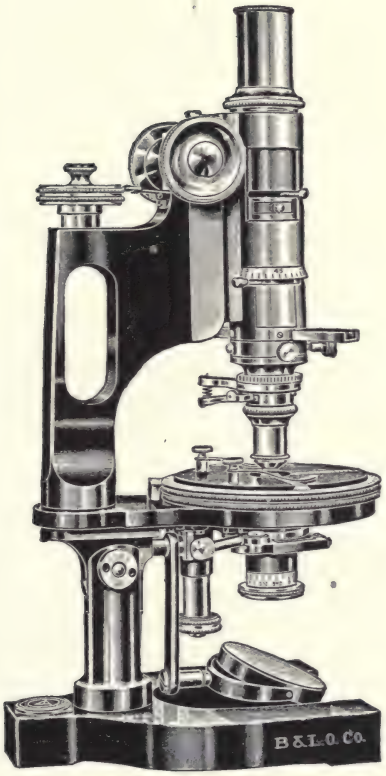



FIG. 324.

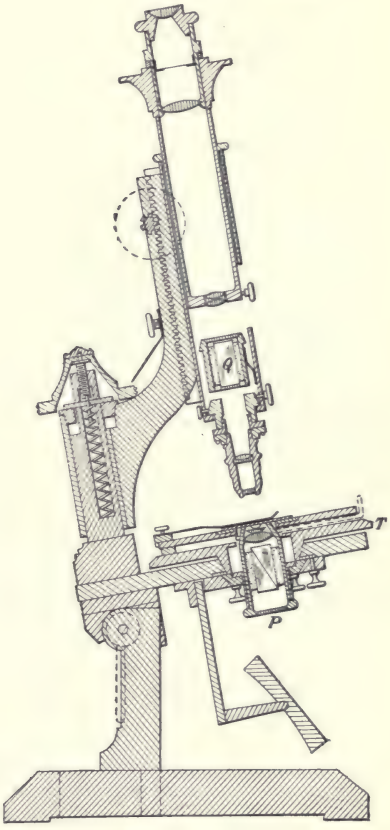



FIG. 325.

**Polarizing Microscope.**—As indicated on page 99, the microscope used by mineralogists (Fig. 324) differs materially from the instruments used by biologists and other scientists, in that the stage rotates in the horizontal plane. It is also equipped with devices, called *Nicol prisms*, which permit objects to be studied in polarized light. Figure 325 shows a

polarizing microscope in cross-section. $T$ is the rotating stage. Below the stage is $P$, a Nicol prism for the production of polarized light, see page 99. It is called the *polarizer*. Another Nicol prism, $Q$, is placed above the stage in the tube of the microscope. This is called the *analyzer*. This second Nicol prism is mounted upon a slide so that it may be easily removed from the tube. Both nicols can usually be rotated.

There are several classes of observations which can be made with a mineralogical microscope, viz.:

I. General observations in ordinary light.

II. Observations in polarized light.

($a$). Parallel polarized light.
($b$). Convergent polarized light.

## I. GENERAL OBSERVATIONS IN ORDINARY LIGHT

**Centering.**—In order to use the rotating stage to advantage, its center must obviously lie in the vertical axis passing through the tube when the stage is rotated. To permit of centering, the tube is provided with two screws placed at right angles to each other directly above the objective. These screws displace the tube laterally.

FIG. 326.—Frederick E. Wright (1877—). Geophysical Laboratory, Washington, D.C. American authority on the polarizing microscope and its applications.

Centering is most readily accomplished by placing on the stage an object glass with a dark speck or small spot of ink, and noting the position of the speck with respect to the dark lines crossing the field. These are called *cross hairs* and their intersection indicates the center of the field of vision. The object glass should then be carefully moved until the speck is at the intersection of the cross hairs. If the stage is centered, the speck will remain at the intersection when the stage is rotated. If it is not centered, the speck will move in a circular path, the center of which, $o$, lies to one side of the center of the field of vision, $I$ (Fig. 327). The stage should then be rotated until the speck appears to lie upon one of the cross hairs, $A'$, and the screw parallel to it, $C$, should then be turned until the speck has moved from $X$ to $Y$, that is, one-half the distance to the intersection of the cross hairs. The object glass is now moved so that the speck is again at the center of the field, and the stage rotated. The speck will describe the path indicated by the smaller circle. When it apparently lies on the second cross hair, $P'$, the screw, $D$, should be turned

until it has moved from $X'$ to $Y'$, again one-half the distance to the center of the field. Upon bringing the speck to the center of the field and rotating the stage, it will be found that it has been centered; that is, the spot will remain stationary. Ordinarily, it is necessary to repeat this process several times before the stage is perfectly centered.

On some microscopes the centering screws are not parallel to the cross hairs, as in Fig. 327, but are placed diagonally, as shown in Fig. 328.

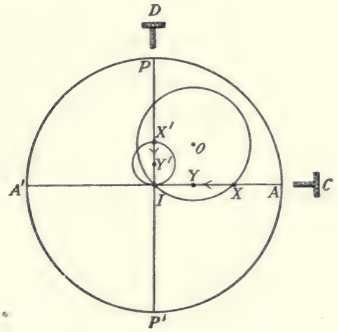



Fig. 327.

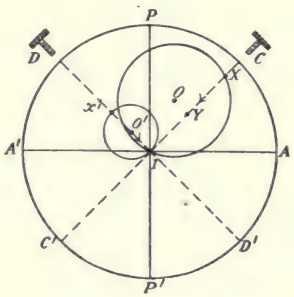



Fig. 328.

When this is the case the speck should be brought into the diagonal positions indicated by $X$ and $X'$, and the adjustments made by the screws $C$ and $D$, as described above.

**Measurement of Angles.**—In measuring plane angles between crystal edges or between cleavage directions, the intersection of the edges is brought to the center of the cross hairs and the microscope centered, as described above. The stage is now rotated until one edge is parallel to one cross hair, $A$, and a reading made on the graduated scale of the stage. See Fig. 329. The stage is then rotated until the other edge is parallel with the same cross hair, $AA'$. The difference between the two readings, angle $m$, is the supplement of the plane angle under consideration drawn in heavy lines.

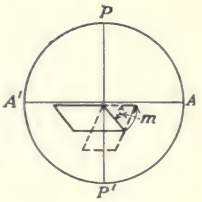



Fig. 329.

**Becke Method.**—The indices of refraction of solids, either in the form of rock or mineral sections or fragments, may be easily determined by using the method devised by Becke (Fig. 330). This method depends upon total reflection of light, as illustrated in Fig. 331. Let $A$ and $B$ be two solids in contact, $B$ having a higher index of refraction than $A$. If the microscope be focused upon the contact, a band or line of light will be observed at $SO$, which will move toward $B$ when the tube is raised. On lowering the tube it moves toward $A$. This band or zone is caused by the concentration of light on one side of the contact, for all rays of light in $A$, which impinge upon the contact,

will pass into $B$, irrespective of the angle of incidence, $i$. Thus, the ray $x$ will emerge as $OM$. But when light passing through $B$ impinges upon the contact, the size of the angle of incidence is of great importance, for here the passage is from a denser to a rarer medium. In all such cases total reflection will take place if the angle of incidence $i$ is larger than the critical angle. That is, the ray $R$ will emerge as $ST$. As indicated, the raising of the microscope tube will displace the band of light, due to this concentration of rays, toward the substance with the higher index. The intensity of this line of light is often accentuated by lowering the substage of the instrument. Whether or not the index of the substance under investigation is higher or lower than that of a known substance can thus be easily determined.

FIG. 330.—Friederich J. Becke (1855 —). Professor of mineralogy and petrography in the University of Vienna.

The indices of refraction of fragments can be determined by embedding them in liquids of known indices, and the movement of the band of light noted. The operation is repeated with different liquids, until one is found with an index equal to that of the fragment. In this case the fragment is invisible, or only slightly visible, and is said to have *low relief*. When the difference between the indices of the fragment and the liquid is quite large, the fragment appears rough with a dark border, and is said to have *high relief*. For this purpose the following liquids are serviceable:

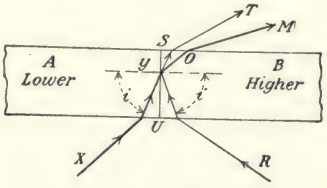



FIG. 331.

| | |
|---|---|
| Water | 1.3336 |
| Petroleum | 1.45 |
| Turpentine | 1.4721 |
| Xylol, meta | 1.502 |
| Clove oil | 1.544 |
| Cinnamon oil | 1.6026 |
| $\alpha$ monobromnaphthalene | 1.6495 |
| Methyelene iodide | 1.7421 |
| Sulphur in methylene iodide | 1.8 |

A set of standardized liquids with indices which vary regularly is practically indespensible in determining the indices of refraction of small fragments. Wright suggests the use of the following:

| Mixture of | Index |
|---|---|
| Petroleum and turpentine | 1.450–1.475 |
| Turpentine and clove oil | 1.480–1.535 |
| Clove oil and $\alpha$ monobromnaphthalene | 1.540–1.635 |
| $\alpha$ monobromnaphthalene and $\alpha$ monochlornaphthalene | 1.640–1.655 |
| Monochlornaphthalene and methylene iodide | 1.660–1.740 |
| Sulphur dissolved in methylene iodide | 1.740–1.790 |
| Methylene iodide, antimony iodide, arsenic sulphide, antimony sulphide, and sulphur | 1.790–1.960 |

## II. OBSERVATIONS IN POLARIZED LIGHT

**Nature of Polarized Light.**—According to the undulatory theory, light is assumed to be a form of energy transmitted in waves in the ether, which pervades all things and space. The propagation of light takes place according to the laws of wave motion, the ether particles vibrating at right angles to the direction of propagation. The velocity of propagation has been determined to be about 186,000 miles per second.

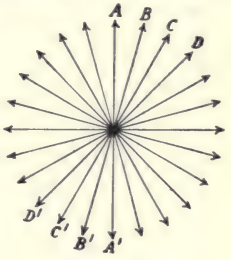


FIG. 332.

In the case of ordinary light, the vibration of the ether particles takes place in a plane at right angles to the direction in which the light is propagated, but the vibration direction in this plane is constantly changing. If in Fig. 332, a ray of light is considered as being propagated perpendicular to the plane of this page, then the vibration of the ether particles will be successively in the directions $AA'$, $BB'$, $CC'$, and so forth. This is shown in perspective in Fig. 333, which must be conceived as revolving about $AB$ as an axis.

In plane polarized light, the vibrations take place in a definite direction within the plane and at right angles to the direction of propagation. Plane polarized light may be produced in three ways: (1) by absorption, (2) by reflection, and (3) by refraction.

**Polarized Light by Absorption.**—When ordinary light passes through a plate of colored tourmaline cut parallel to the *c* axis, the light which emerges is plane polarized. Its vibrations are commonly assumed to be parallel to the *c* axis. This is illustrated in Fig. 334. Ordinary light emanating from $A$ vibrates in all directions, but in order to pass through the tourmaline plate $xy$, it must only vibrate parallel to the $c$ axis, that is, parallel to $xy$. Light vibrating in other directions is absorbed by the tourmaline. Hence, $op$ represents a ray of plane polarized light produced by absorption.

If a second plate of tourmaline $x'y'$ be placed in the path of $op$ so that the direction of its $c$ axis is perpendicular to that of the first plate $xy$, we shall observe that the ray $op$ vibrating vertically will now be entirely absorbed by the second tourmaline, the favorable direction for the pas-

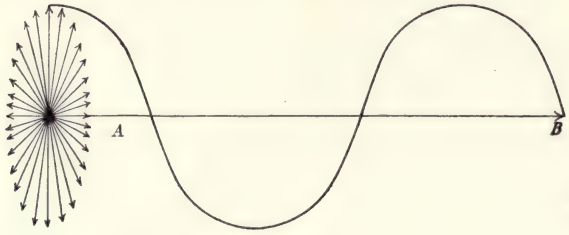



FIG. 333.

sage of light, $x'y'$, being horizontal. This method for the production of polarized light is not commonly used in scientific instruments.

**Polarized Light by Reflection.**—When ordinary light is reflected from a smooth surface, such as glass, it is found to be partially plane polarized,

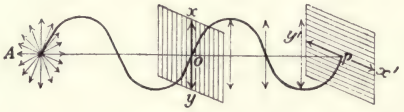



FIG. 334.

the vibration directions being at right angles to the direction of propagation. In Fig. 335, the plane $ABCD$, containing the incident and reflected rays $ax$ and $xy$, is called the plane of polarization. The plane, $MPON$, in which the polarized ray $xy$ vibrates, is called the plane of vibration.

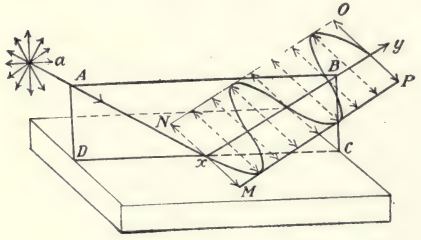



FIG. 335.

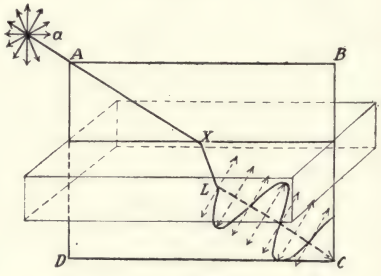



FIG. 336.

It is perpendicular to the plane of polarization. This method of producing polarized light was formerly used much more extensively than at present.

**Polarized Light by Refraction.**—A portion of the ray $AX$ in Fig. 336, may enter the plate at $X$ and be refracted. Upon emerging as the ray $LC$, it is partially plane polarized. The vibrations are now exe-

cuted in the plane of polarization, and are perpendicular to the vibration directions characteristic of polarization by reflection. The polarized light used in the mineralogical microscope is commonly produced by refraction. For this purpose, a *nicol prism* is usually employed.

**Nicol Prism.**—This consists of a cleavage piece of clear, transparent calcite, commonly called Iceland or double spar. It is usually somewhat elongated as shown in Fig. 337. The natural angles of 71° at *A* and *F* are reduced by grinding to 68°. The prism is then cut in two by the plane *CD*, which is at right angles to the new end faces *BC* and *DE*. After the two parts have been polished, they are cemented together with Canada Balsam *DC*, which has an index of refraction of about 1.54.

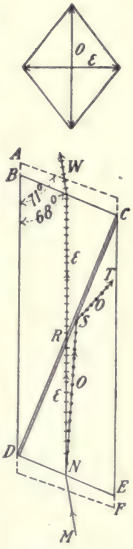


FIG. 337.

If ordinary light be allowed to fall upon *DE* in the direction of *MN*, it will be resolved into two rays, since calcite is a doubly refractive substance. Each of these rays is plane polarized. One of the rays is called the ordinary ray, *o*. It has a constant index of refraction of 1.658. The other ray is termed the extraordinary ray *e* and its index of refraction varies from 1.486, when propagated at right angles to the *c* axis, to 1.658 when parallel to the *c* axis. In the direction *NR*, its index of refraction approximates that of the Canada balsam.

The ordinary ray *o* with an index of refraction 1.658 impinges upon the film of Canada balsam at *S* with an angle of incidence which is greater than the critical angle. It is, hence, totally reflected in the direction of *ST*. It, therefore, does not emerge at the upper end of the nicol prism, but is absorbed by the side of the case in which the nicol is mounted.

The extraordinary ray *e*, however, pursues a path in the nicol indicated by *NR*. For this direction the index of refraction of the extraordinary ray is approximately the same as that of the Canada balsam and the ray, therefore, passes through the balsam with little, if any, deviation. It emerges from the prism at *W*, and is plane polarized with vibrations parallel to the short diagonal of the end rhombohedral face of the nicol. This simple device is very efficient for producing plane polarized light by refraction.

Nicol prisms are used very extensively in polarizing microscopes and other crystallographic-optical instruments. In microscopes, a nicol prism, called the *polarizer*, is placed below the stage, while a second, the *analyzer*, is mounted in the tube above the objective (see page 103). The nicols can be rotated in the horizontal plane. Observations may be made with the vibration directions of both nicols either parallel or at right angles to each other. When the directions are perpendicular to

each other, the nicols are said to be *crossed*. Observations with crossed nicols are much more important than those made with *parallel* nicols.

**Parallel and Convergent Polarized Light.**—Observations may be carried out with the rays of polarized light passing through the substances parallel to the axis of the microscope tube, or the rays may be made to converge in the substance by means of suitable condensing lenses. We may hence speak of observations in (*a*) *parallel polarized light*, and in (*b*) *convergent polarized light*.

Since solids may be classified optically as isotropic and anisotropic, the effects of parallel and convergent polarized light upon each of these groups will be considered. It must be remembered that anisotropic substances can be subdivided into uniaxial and biaxial groups.

**Behavior of Isotropic Substances.** (*a*) *In Parallel Polarized Light with Crossed Nicols.*—If the analyzer is removed from the microscope tube and an isotropic substance, either an amorphous substance or a crystal of the cubic system, be viewed on the microscope stage, it will be noted that the field of vision is illuminated. It remains illuminated for all positions of the stage, for the polarized light emerging from the polarizer passes through an isotropic substance without change. However, when the analyzer is replaced with its vibration direction perpendicular to that of the polarizer, the field of vision is dark and remains so upon rotating the stage. This is due to the fact that the light emerging from the object on the stage vibrates parallel to the vibration direction of the polarizer. This direction, however, is at right angles to that of the analyzer, the nicols being crossed, and hence no light passes through the upper nicol. All isotropic substances, therefore, appear dark between crossed nicols. This observation is very easily made and serves to distinguish isotropic substances from those which are optically anisotropic or doubly refractive.

FIG. 338.

(*b*) *In Convergent Polarized Light with Crossed Nicols.*—When substances are studied in convergent polarized light, the rays of light pass through the substance inclined to the axis of the microscope; that is, they tend to converge (Fig. 338). Convergent light is easily obtained by using an objective of high magnification and inserting a condensing lens below the microscope stage.

Isotropic substances appear dark in convergent light between crossed nicols for the same reasons as given above. That is, between crossed nicols they are always dark in both parallel and convergent light.

**Behavior of Uniaxial Substances in Parallel Polarized Light with Crossed Nicols.** (*a*) *Sections perpendicular to the c Axis.*—When the analyzer is removed, these sections of uniaxial crystals, that is, either crystals of the hexagonal or tetragonal systems, will appear light and

remain so for all positions of the stage. When the analyzer is replaced with its vibration directions perpendicular to that of the polarizer, the field is dark and remains so when the stage is rotated. This behavior of hexagonal and tetragonal crystals is the same as for isotropic substances, as discussed above. This is due to the fact that the light passing through the crystal, or through the section, is parallel to the *c* axis which is an isotropic direction. For this particular direction, uniaxial substances behave in parallel polarized light as though they were isotropic.

(*b*) *Sections Parallel or Inclined to the c Axis.*—When these sections are viewed with the analyzer removed, the field of vision is illuminated. When the analyzer is replaced and the stage rotated, the field is four times light and four times dark during a complete rotation, provided the nicols are crossed. That is, when viewed in daylight or white artificial light, interference colors are seen four times during a complete rotation. The positions of greatest darkness or extinction indicate the vibration directions of the rays passing through the section or crystal. When the vibration directions of the crystal and those of the nicols are parallel, the field of vision is dark. This is illustrated in Fig. 339 where $PP'$ and $AA'$ are the vibration directions of the polarizer and analyzer respectively, and $RR'$ and $SS'$ those of the crystal. $PP'$ and $RR'$ being parallel, light from the polarizer passes through the crystal without change in vibration direction and enters the analyzer but does not emerge, the favorable direction for passage through the upper nicol being $AA'$.

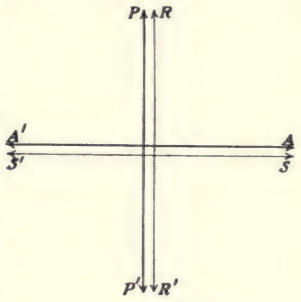



FIG. 339.

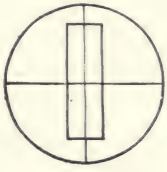


FIG. 340.

FIG. 341.

The cross hairs of the microscope are parallel to the vibration directions of the nicols and are used for the determination of the extinction or vibration directions in the crystal or section. Extinction may take place when the cross hairs are parallel or perpendicular to the edges of the specimen as in Fig. 340. When this is the case, the crystal is said to have *parallel extinction.* Uniaxial substances may also possess *symmetrical extinction* as illustrated in Fig. 341.

(*c*) *Determination of Indices of Refraction.*—The position of extinction is found as indicated above. The analyzer is then removed and the Becke

test applied (see page 105). In this way, the index of refraction of the ray vibrating parallel to the vibration direction of the polarizer is determined. On rotating the stage through 90°, the index of refraction for the second vibration direction can be determined. The ray vibrating parallel to the *c* axis is termed the *extraordinary ray e;* the one vibrating at right angles to it, the *ordinary ray o.* When the index of refraction of *e* is larger than that of *o*, the crystal is said to be optically *positive;* when smaller, optically *negative* (see page 102).

(*d*) *Interference Colors.*—When the vibration directions in the crystal are not parallel to those of the nicols, the field shows in general an interference color, provided the crystal is viewed in either daylight or artificial white light. The color is due to the fact that the light from the polarizer *PP'* is resolved into two rays vibrating parallel to *xx'* and *yy'*, the vibrations direction of the crystal (Figs. 342 and 343). The two rays in the crystal travel with different velocities and when they emerge the slow ray naturally lags behind the faster. On entering the

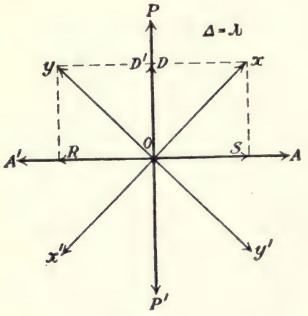



Fig. 342.

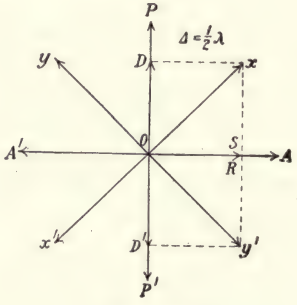



Fig. 343.

upper nicol, each of these rays is further resolved into two rays vibrating parallel to the vibration directions of the *o* and *e* rays of the analyzer. As indicated on page 109, only the latter of these, namely the two vibrating parallel to the *e* ray, emerge from the analyzer. But these two emergent rays (*OS* and *OR*) vibrating in the same plane, travel with different velocities. Interference of light is thus brought about, and with crossed nicols when the phasal difference of the two rays is equal to a whole wave length $\gamma$, or some whole multiple thereof, destructive interference results (Fig. 342). When the phasal difference is a half wave length, $\frac{1}{2}\gamma$, or some odd multiple thereof, the rays reinforce each other (Fig. 343).

As the phasal differences for the component colors of white light will be of both these types, certain portions of the white light passing through the crystal are destroyed, while other portions are intensified causing the light which emerges to be colored. The field of vision shows therefore what is commonly designated as an interference color. The

character of the color depends upon (1) *strength of double refraction of the substance,* (2) *position of the plate with regard to the c axis and* (3) *thickness of the plate.* When monochromatic light instead of daylight is used, the field will be dark as before, if the vibration directions in the substance and nicols correspond. In intermediate positions, the field will be illuminated by light of the particular color employed.

(*e*) *Determination of the Fast and Slow Rays.*—The position of extinction is first determined and the stage then rotated so that the extinction directions cross the field diagonally; that is, they make angles of 45° with the cross hairs (Fig. 344). This is the position of most intense illumination and color. Into the slot of the microscope tube, which is directly above the object, a gypsum or selenite test plate is now inserted. When viewed alone between cross nicols, the test plate yields an interference color which is usually designated as the *sensitive red tint.* This tint is easily changed to either blue or yellow by the action of the crystal on the stage. If it is changed to blue, it means that the vibration directions of the test plate and those of the crystal correspond; that is, the slow ray in the test plate is over the slow ray in the crystal, and fast over fast. Now note the direction of the marked ray on the test plate which is usually given as *a* or $\mathfrak{a}$. This is the fast ray and the vibration direction at right angles to it is obviously that of the slow ray, which is commonly designated as *c* or $\mathfrak{c}$. In this way, the direction of the corresponding rays are easily recognized in the crystal. If, however, the sensitive red tint is changed to yellow, instead of blue, it means that the fast ray of the test plate is over the slow ray of the crystal, and, vice versa.

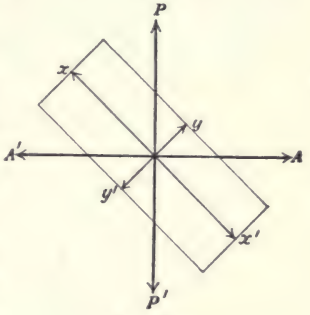


FIG. 344.

(*f*) *Order of Interference Colors.*—The interference colors may be bright and vivid and are then said to be of a *low or medium order,* or they may be hazy and dull and are of the *higher orders.* It is well in determining the order of interference colors to study an interference color chart. When the color approximates white, it is characterized as being *white of the higher order.* When sections of different substances have the same thickness, some indication of the strength of double refraction, or birefringence, can be obtained from the character of the interference colors, for the stronger the double refraction, the higher the resultant colors. When dealing with one and the same substance, the thicker sections or crystals will show colors of the higher orders.

**The Behavior of Uniaxial Crystals in Convergent Polarized Light with Crossed Nicols.** (*a*) *Sections Perpendicular to the c Axis.*—In uniaxial substances all rays of light inclined to the *c* axis are resolved into two

rays, *o* and *e*, which travel with unequal velocities. These rays interfere therefore on emerging from the substance, as indicated in Fig. 345. The phasal difference between these rays increases with the inclination of the incident rays to the *c* axis. Hence, at *OP*, which corresponds to the direction of the *c* axis, the phasal difference will be zero. Accordingly, the phasal difference increases as the distance of emergence from *P* grows larger. The increase is the same for all directions. Wherever the phasal difference $\Delta = \frac{n}{2}\lambda$, where $n$ is odd, reinforcement of light takes place. Where $\Delta = n\lambda$, $n$ being any whole number, destructive interference results. Therefore, along any diameter through the field of vision, we will

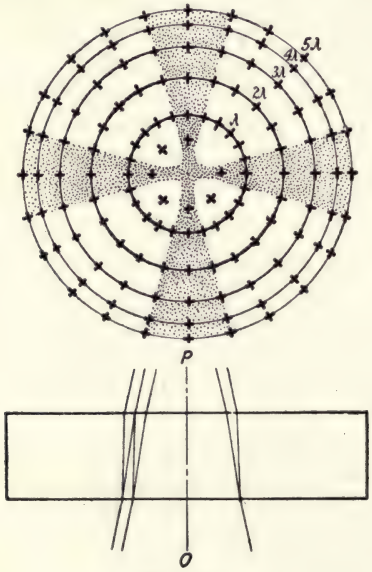



FIG. 345.

observe darkness at the center *P*, and at equal distances on either side of *P* the same interference colors will appear when daylight or artificial white light is used. In uniaxial crystals, all directions perpendicular to the *c* axis are optically the same. Hence, the interference colors appear as a series of concentric rings. The colors are brighter and more vivid near the center of the field and gradually fade as the distance from the center increases. These isochromatic circles are farther apart near the center of the field and closer together toward the periphery. In monochromatic light, a series of light and dark circles will be observed (Figs. 346 and 347).

It will be further observed that a dark cross lies superimposed upon the isochromatic circles. The cross occurs where the vibration directions of the substance correspond to those of the nicols, for as has been pointed out previously, in such instances the field is dark. The isochromatic

circles and the dark cross constitute what is called a *uniaxial interference figure.*

The uniaxial interference figure remains unchanged when the stage is rotated, for all directions through the substance perpendicular to the *c* axis are alike optically. In order to observe interference figures, it is

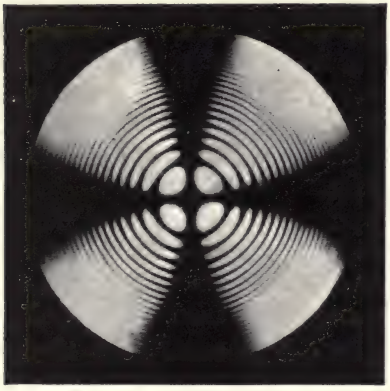


FIG. 346.

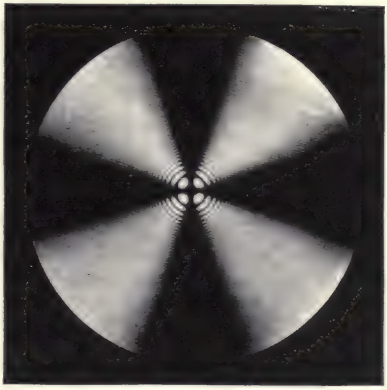


FIG. 347.

necessary to either remove the eyepiece of the microscope, or to insert an auxiliary lens called the *Bertrand lens* into the tube above the analyzer. In the first case, the figure is small and appears far down in the tube. It is, however, usually quite distinct. In the second case, the figure is much larger, but generally more hazy.

FIG. 348.

(*b*) *Sections Inclined to the c Axis.*—Sections of this character show only a partial interference figure in convergent light. The more nearly the section is parallel to the base, the more will the observed figure approximate the normal figure; and the greater the departure from this parallelism, the more the figure will be eccentric and incomplete. This is shown

by Fig. 348. When the stage is rotated, the arms of the dark cross move across the field parallel to the cross hairs and in the same direction as the movement of the stage. This observation is of great importance in distinguishing certain uniaxial from biaxial figures (see page 119).

(*c*) *Strength of Double Refraction Determined from Uniaxial Interference Figures.*—The number of isochromatic circles may serve to estimate the strength of double refraction or birefringence. When sections have the same thickness, substances with strong double refraction will show more rings than those possessing weak birefringence. Thickness also increases the number of rings (Figs. 346 and 347). In extremely thin sections no rings at all are sometimes visible. This is especially true of substances with very weak birefringence.

(*d*) *Character of Double Refraction Determined from Uniaxial Interference Figures.*—If the mica test plate be inserted in the slot of the microscope tube, it will be observed that the interference figure breaks up and two distinctly black spots appear near the center of the field. The position of these spots with respect to the vibration direction marked on the test

Fig. 349.

Fig. 350.

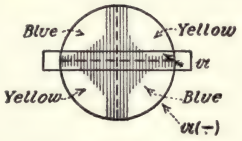



Fig. 351.

plate should be noted. If a line joining these spots is parallel to the c direction (slow ray in test plate), the substance is optically *negative* (Fig. 349). When the gypsum or selenite test plate is used, two blue spots appear. If the line joining these blue spots is parallel to the a direction of the gypsum test plate (fast ray in test plate), the substance is said to be optically *negative* (Fig. 350). In case of optically *positive* substances, the line joining the black and blue spots crosses the marked direction on the plates referred to above, (Fig. 351). These observations are based upon the fact that when like directions in the test plates and substances are over one another, the double refraction is increased. When the corresponding directions are unlike, for example, fast ray over slow ray, and vice versa, a reduction in double refraction results.

**General Statement Regarding Biaxial Crystals.**—As indicated on page 102, all crystals of the orthorhombic, monoclinic, and triclinic systems are biaxial and possess three principal optical directions at right angles to each other. In the orthorhombic system these optical directions correspond to the three crystallographic axes. Monoclinic crystals have only one of these directions fixed, namely, by the *b* crystallographic axis. In the triclinic system, there is no relationship between

the orientation of the principal optical directions and the crystallographic axes. The principal optical direction which bisects the acute angle between the two isotropic directions, or the optic axes, is called the acute bisectrix, $Bx_a$. The obtuse bisectrix $Bx_o$, bisects the obtuse angle of the optic axes. These bisectrices are the vibration directions of the rays traveling with the greatest and least velocities. The direction at right angles to the plane of these bisectrices is termed the *optic normal*, $\mathfrak{b}$.

Crystals are said to be optically *positive* or *negative*, depending upon whether the acute bisectrix is the vibration direction of the slow or fast rays, $\mathfrak{c}$ or $\mathfrak{a}$ respectively. The direction of the optic normal is commonly designated as $\mathfrak{b}$.

**Behavior of Biaxial Crystals.**—*A. In Parallel Polarized Light with Crossed Nicols* (*a*) *Any Section.*—All sections of biaxial crystals, with the exception of those perpendicular to an optic axis, are four times light and four times dark during a complete rotation of the stage. The extinction may be either parallel, symmetrical, or inclined to an edge or crack of the crystal or section (Figs. 340, 341 and 352). In the case of orthorhombic substances, the extinction is either parallel or symmetrical. Monoclinic substances possess both parallel and inclined extinctions; that is, sections parallel to the *b* axis have parallel extinction, while all other sections have inclined or oblique extinction. Maximum obliquity is observed on sections perpendicular to the *b* axis. In triclinic substances all extinctions are inclined.

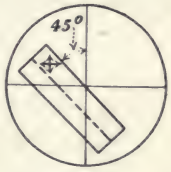


FIG. 352

(*b*) *Sections Perpendicular to an Optic Axis.*—These sections do not extinguish when the stage is rotated between crossed nicols, but remain uniformly illuminated. In convergent light, an interference figure is observed (see Fig. 359, page 119).

*B. In Convergent Polarized Light with Crossed Nicols* (*a*) *Sections Perpendicular to the Acute Bisectrix, $Bx_a$.*—These sections show an interference figure consisting of two series of oval-like curves upon which two dark brushes are superimposed. In the *normal* position, that is, when the plane including the optic axis and the direction at right angles to it are parallel with the cross hairs, the interference figure resembles Fig. 353. In white light the curves are colored, while in monochromatic light they are alternately light and dark. The distance between the optic axes or "eyes" gives some indication of the size of the angle of the optic axes. The closer together the "eyes" are, the smaller is the angle (Fig. 354) and vice versa. The angle of the optic axes is constant for any given substance and is independent of the thickness of the section, provided the temperature remains the same. From the number of curves in the interference figure, some idea of the double refraction may be obtained, for the stronger the double refraction the larger the number

of the curves in the field of vision, provided the sections are of the same thickness.

The optical properties of biaxial crystals are very complex, and only an elementary and incomplete explanation of the formation of these interference figures will be given. The black cross or hyperbolic brushes

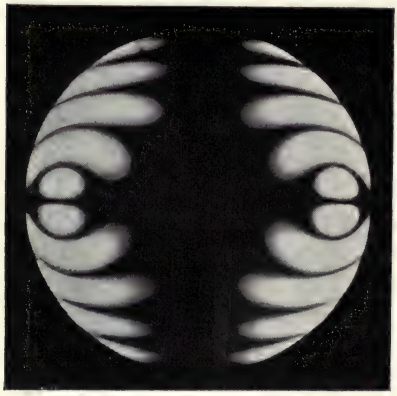


FIG. 353.

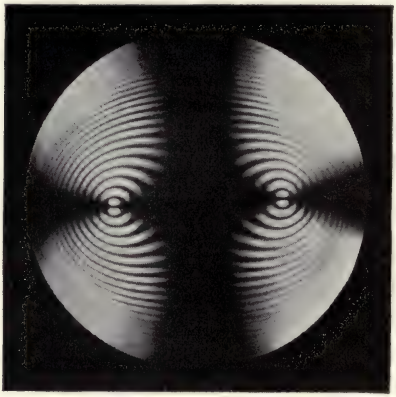


FIG. 354.

appear wherever the vibration directions of the emergent rays are parallel to those of the nicols. At all other points of the section the emergent rays have vibration directions which are inclined to those of the nicols and interference of light, as explained on page 112, will therefore take

FIG. 355.

FIG. 356.

place. As these vibration directions change most rapidly around the optic axes, the curves there will be smaller and closer together than elsewhere. These curves are unaltered as the stage is rotated. The dark brushes, however, change. Compare Figs. 355 and 356.

The positive and negative character of biaxial crystals may be determined from the interference figure by using the mica or gypsum test

plates, as described on page 116. When the spots are in the same quadrants as the marked directions on the test plate (c, mica; or a, gypsum) the substance is negative, and positive in the opposite quadrants.

(*b*) *Sections Inclined to the Acute Bisectrix, $Bx_a$.*—These sections show a partial interference figure, usually only one optic axis or "eye" and a

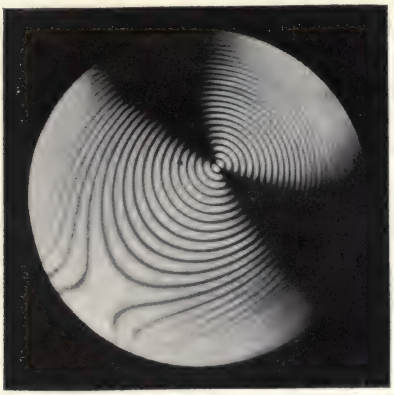


FIG. 357.

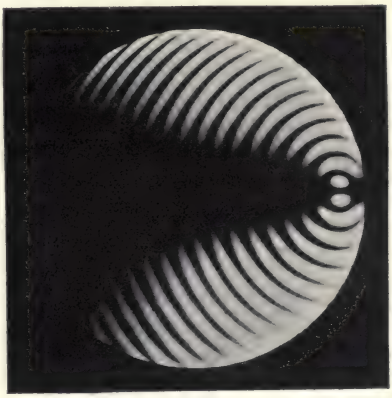


FIG. 358.

portion of the brushes being visible (Figs. 357 and 358). The brushes always move in a direction opposite to that of the stage.

(*c*) *Sections Perpendicular to an Optic Axis.*—These sections show the emergence of an optic axis, the observed interference figure being illustrated by Fig. 359. This figure does not remain stationary when

FIG. 359.

the stage is rotated, as is the case with interference figures of uniaxial substances, page 115.

(*d*) *Sections Parallel to the Plane of the Optic Axes.*—Sections of this character do not in general show interference figures, especially if studied in white light.

(*e*) *Dispersion of the Optic Axes, $r > v$ or $r < v$.*—In Fig. 356 illustrating biaxial interference figures, the size of the angle of the optic axes is indicated by the distance between the centers of the eyes. When white light is used and the interference figures are viewed in the 45° or diagonal position, the hyperbolic brushes show red and blue or violet fringes. These fringes are especially distinct at $r$ and $v$ as shown in Figs. 360 and 361. This is due to the fact that the size of the angle of the optic varies with the color. In some cases, the angle for red is larger than for violet, and vice versa. If red appears on the convex side of the hyperbolic brushes, it means that the optic angle for red is larger than for blue or violet; that is $r > v$. On the other hand, if violet is observed on the convex side of the brushes, the angle for violet is the larger, namely $v > r$. That is, the dispersion of the optic axes is directly opposite to what appears to be the case from the position of the colors in the interference figure. This is due to the fact that from the white

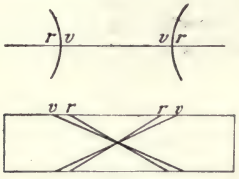



FIG. 360.

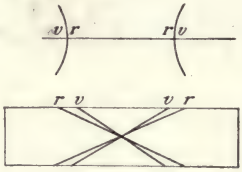



FIG. 361.

light travelling along the optic axes of the various colors, certain components are eliminated and other intensified. Hence, where the axes for red light emerge, say at $r$ in Figs. 360 and 361, red will have been eliminated, and the resultant light will be violet. At $v$, violet has been lost, and in the interference figure red will appear at the corresponding positions. The observations of the character of the dispersion of the optic axes is best made with the interference figure in the diagonal position on any section where a portion of a hyperbolic brush is distinctly visible near the center of the field. Dispersion aids materially in identifying biaxial substances.

**Circular Polarization.**—Some substances show circular polarization; that is, they rotate the plane of polarization. The most notable of such substances among the common minerals is quartz. As is well know, quartz occurs in enatiomorphous crystals; that is, in right and left hand crystals (see Figs. 190 and 191, page 53). This type of development is also observed on crystals of tartaric acid, cane sugar, and sodium chlorate. In some particulars, the behavior of substances possessing circular polarization is unique. The effect of circular polarization in uniaxial crystals only will be considered.

*A. Porallel Polarized Light and Crossed Nicols* (*a*) *Sections Cut Perpendicular to the c Axis.*—As the *c* axis in these substances is not an isotropic

direction, sections cut perpendicular to it do not extinguish between crossed nicols, but remain uniformily illuminated when the stage is rotated.

(*b*) *Sections cut parallel or inclined to the c axis.* These sections behave like those described on page 115.

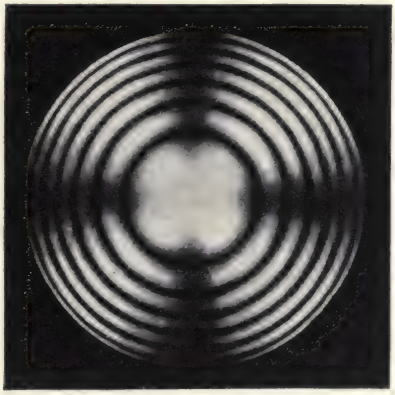


FIG. 362.

*B. Convergent Polarized Light and Crossed Nicols. Sections Cut Perpendicular to the c Axis.*—An interference figure quite analogous to the regular uniaxial interference figure is obtained (Fig. 362). It will be observed that the dark brushes do not extend entirely across the center of the figure. By rotating the upper nicol, the character of the

FIG. 363.

FIG. 364.

rotation of polarization may be determined. That is, whether it is to the right or left. If the upper nicol is rotated in the proper direction, the circles of the figure enlarge; but if it is rotated in the opposite direction to that of the rotation of the plane of polarization, the circles contract. By using the mica test plate, a two-armed spiral is obtained. The direction

of rotation, being indicated by the directions of the arms (Figs. 363 and 364). By placing two sections of quartz of the same thickness over one another, a figure with a four-armed spiral results. These are the spirals of Airy (Figs. 365 and 366). The direction of the arms of the spirals indicates the character of the rotation in the lower section.

**Twin Crystals.**—The fact that crystals are twinned is easily recognized in polarized light, especially if they are anisotropic.

FIG. 365.

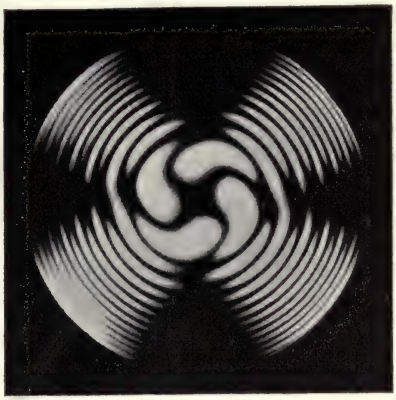


FIG. 366.

*a. Polarized Light and Crossed Nicols.*—Anisotropic crystals showing twinning do not extinguish uniformly. Certain portions of the crystal may be dark, while other portions are light, when the stage is rotated. Figures 367 and 368 show the behavior of contact twins, and Fig. 369 that of a section with polysynthetic twinning. Obviously, twinned crystals of isotropic substances will have no effect upon polarized light.

*b. Convergent Light and Crossed Nicols.*—In properly oriented sections, interference figures may be observed as shown in Fig. 370.

FIG. 367.

FIG. 368.

FIG. 369.

FIG. 370.

**Pleochroism.**—The absorption of light in colored sections and crystals of uniaxial and biaxial substances varies with direction. In the case of uniaxial substances, there are two principal colors for transmitted light. These colors are obtained when the light vibrates either parallel and perpendicular to the **c** axis. Uniaxial substances are therefore said to be *dichroic*. In biaxial crystals there are three principal colors cor-

responding to the three principal optical directions at right angles to each other. Biaxial substances are therefore *trichroic.*

Pleochroism is easily recognized under the microscope by first determining the extinction directions of the section or crystal under consideration. Then bring one of these directions parallel to the vibration direction of the lower nicol or polarizer. Now remove the upper nicol and observe the color. Rotate the stage through 90° and note the change in color. Strongly pleochroic substances show marked changes in color when studied in this way.

Isotropic substances, that is, those which are amorphous or belong to the cubic system, do not show pleochroism.

**Summary.**—*Behavior of sections, crystals, or fragments in parallel light between crossed nicols.*

- All sections remain dark through 360°.
  - Isotropic
    - (*a*) No regular outline, structure, cleavage, or etch figures. — Amorphous
    - (*b*) Regular outline, structure, cleavage, and etch figures. — Cubic
- Not all sections remain dark through 360°. Some are four times light and dark, others remain uniformly light.
  - Anisotropic
    - (*a*) Isotropic and doubly refractive sections. The first show an uniaxial interference figure in convergent light.
      - Hexagonal. Isotropic sections are trigonal or hexagonal in outline.
      - Tetragonal. Isotropic sections are tetragonal or ditetragonal in outline.
    - (*b*) Sections either extinguish regularly or remain uniformly light. The latter show the emergence of an optic axis in convergent light.
      - Orthorhombic. All sections show parallel or symmetrical extinction.
      - Monoclinic. Sections show parallel, symmetrical or inclined extinction.
      - Triclinic. All sections show inclined extinction.

**Order of Procedure and Methods for Recording Observations.** In studying sections, crystals, or fragments under the polarizing microscope, the following order for making determinations is suggested:

*Parallel Polarized Light*

1. Isotropic or anisotropic.
2. Index of refraction; higher or lower than Canada balsam or the liquid in which substance is embedded, if in fragments.

3. Outline of section or crystal. Cleavage cracks.
4. Extinction directions—parallel, symmetrical, or inclined. Measurement of extinction angles.
5. Determination of fast and slow rays.
6. Order of interference colors. Double refraction.
7. Pleochroism.

*Convergent Polarized Light*

1. Uniaxial or biaxial figure. Orientation.
2. If biaxial, note size of optic angle.
3. Positive or negative character.
4. Double refraction.
5. Dispersion.
6. Circular polarization.
7. System. See summary.

Figures 371 and 372 indicate a very good method, suggested by Weinschenk, for recording the various optical properties of substances, as determined under the microscope. In both figures the material represented was in the form of small crystals. The outline of the substance

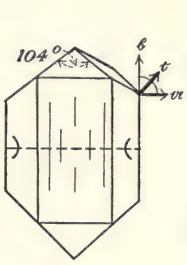



Fig. 371.

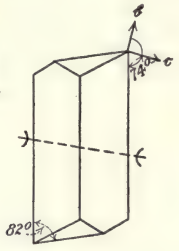



Fig. 372.

should be sketched and important angles measured and their sizes indicated. The direction of cleavage cracks may be shown as in figure 371. The various extinction directions are shown by arrows. The approximate value of the indices of refraction for these directions can be indicated by lines of different widths; that is, light lines indicate low indices, heavy lines high indices. The strength of double refraction is given by the arc inclosing the vibration directions, which may be drawn light or heavy in accordance with the variation from weak to strong double refraction, or one or more arcs may be used. Pleochroism is shown in connection with the vibration directions, the colors being designated. The location of the optic axes, size of the optic angle, and dispersion are all easily indicated.

## CHAPTER XI

## CHEMICAL PROPERTIES

As indicated earlier, minerals have a characteristic chemical composition; that is, when pure they may be either elements or chemical compounds. If minerals are elements, the elements are said to occur *native*. We may thus speak of *native* gold, *native* silver, and *native* copper. Obviously, most of the minerals are chemical compounds.

**Chemical Formulas.**—The determination of the principal chemical constituents of a mineral can frequently be made most rapidly by blowpipe methods. These methods are discussed in detail in the next chapter. The determination of the quantitative composition of minerals belongs to the domain of chemistry, the usual methods of the analytical chemist being employed. The formulas representing the chemical composition of minerals are calculated in exactly the same way as for any other chemical substance. For example, an analysis of chalcopyrite from Müsen, Germany, gave Laspayres the following results:

| | I Analysis, per cent. | | II Atomic weights | | III Combining Ratios | | IV | | V |
|---|---|---|---|---|---|---|---|---|---|
| Cu..... | 34.89 | ÷ | 63.57 | = | 0.5488 | = | 1.020 | = | 1 |
| Fe..... | 30.04 | ÷ | 55.84 | = | 0.5379 | = | 1.000 | = | 1 |
| S..... | 34.51 | ÷ | 32.06 | = | 1.0767 | = | 2.002 | = | 2 |

By dividing the percentages (1) of the various constituents by the atomic weights (II) of the same, their combining ratios (III) are obtained. These can then be expressed in approximate whole numbers (IV and V), from which following ratio results:—

Cu : Fe : S = 1 : 1 : 2. This gives $CuFeS_2$ as the formula for chalcopyrite.

In the case of more complex minerals where the composition is indicated by giving the percentages of the various oxides present, the procedure is the same, with the exception that the molecular weights of the oxides, that is, the sum of the atomic weights of the elements in the same, are used. Thus, Brax in analyzing a beryl from Paavo, Finland, obtained the following:

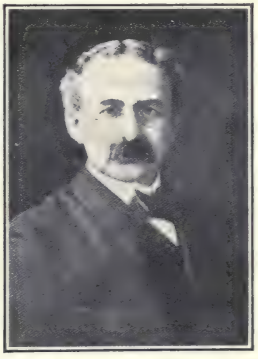


FIG. 373.—Samuel L. Penfield (1856–1906). Professor of mineralogy in Yale University (1893–1906). Distinguished American chemical mineralogist.

| | I Analysis, per cent. | | II Molecular weights | | III Combining Ratios | | IV | | V |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 66.37 | ÷ | 60.3 | = | 1.1007 | = | 5.843 | = | 6 |
| $Al_2O_3$ | 19.26 | ÷ | 102.2 | = | 0.1884 | = | 1.000 | = | 1 |
| BeO | 14.01 | ÷ | 25.1 | = | 0.5619 | = | 2.983 | = | 3 |

These oxides therefore combine in the following ratio: $BeO : Al_2O_3 : SiO_2 = 3 : 1 : 6$, from which the formula $3BeO.Al_2O_3.6SiO_2$ or $Be_3Al_2Si_6O_{18}$ is obtained.

**Percentage Composition.**—When the formula of a mineral has been established, it is possible to calculate what percentages of the various constituents should theoretically be present. Indeed, the degree of purity of a mineral may often be easily estimated by comparing an analysis with the theoretical percentage composition, calculated from the generally accepted formula. Referring again to the mineral chalcopyrite, the formula of which was calculated above as $CuFeS_2$, we may determine its theoretical percentage composition by ascertaining the percentage the combining weight of a given constituent is of the molecular weight of the mineral as a whole. Thus,

| Constituents | Atomic weights | Combining ratios | Combining weights | Proportion of molecular weight of mineral | Theoretical percentage composition |
|---|---|---|---|---|---|
| Cu | 63.57 | 1 | 63.57 | $\frac{63.57}{183.53}$ = | 34.64 |
| Fe | 55.84 | 1 | 55.84 | $\frac{55.84}{183.53}$ = | 30.42 |
| S | 32.06 | 2. | 64.12 | $\frac{64.12}{183.53}$ = | 34.94 |
| | | | 183.53 (Molecular weight of minerals) | | 100.00 |

Using $Be_3Al_2Si_6O_{18}$ as the formula for beryl, the theoretical percentage composition of the various constituents may be calculated as follows:

| Constituents | Molecular weights of radicals | Combining ratio | Combining weights of radicals | Proportion of molecular weight of mineral | Theoretical percentage composition |
|---|---|---|---|---|---|
| $SiO_2$ | 60.3 | 6 | 361.8 | $\frac{361.8}{539.3}$ = | 67.09 |
| $Al_2O_3$ | 102.2 | 1 | 102.2 | $\frac{102.2}{539.3}$ = | 18.95 |
| BeO | 25.1 | 3 | $\frac{75.3}{539.3}$ (Molecular weight of mineral) | $\frac{75.3}{539.3}$ = | $\frac{13.96}{100.00}$ |

**Names.**—Although chemical names may be assigned to minerals, it has long been common practice to designate them by special or mineralogical names. These mineral names are given for various reasons. In some instances, as in the case of *celestite*, the name refers to the light blue color

## Periodic Classification of the Elements

| Periods | Group O | Group I | Group II | Group III | Group IV | Group V | Group VI | Group VII | Group VIII |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | Hydrogen H = 1.008 | | | | | | | |
| 2 | Helium He = 3.99 | Lithium Li = 6.94 | Beryllium Be = 9.1 | Boron B = 11.0 | Carbon C = 12.00 | Nitrogen N = 14.01 | Oxygen O = 16.00 | Fluorine F = 19.0 | — |
| 3 | Neon Ne = 20.2 | Sodium Na = 23.00 | Magnesium Mg = 24.32 | Aluminium Al = 27.1 | Silicon Si = 28.3 | Phosphorus P = 31.04 | Sulphur S = 32. 07 | Chlorine Cl = 35.46 | — |
| 4 | Argon A = 39.88 | Potassium K = 39.10 | Calcium Ca = 40.07 | Scandium Sc = 44.1 | Titanium Ti = 48.1 | Vanadium V = 51.0 | Chromium Cr = 52.0 | Manganese Mn = 54.93 | Iron Fe = 55.84 / Cobalt Co = 58.97 / Nickel Ni = 58.68 |
| 5 | — | Copper Cu = 63.57 | Zinc Zn = 65.37 | Gallium Ga = 69.9 | Germanium Ge = 72.5 | Arsenic As = 74.96 | Selenium Se = 79.2 | Bromine Br = 79.92 | — |
| 6 | Krypton Kr = 82.92 | Rubidium Rb = 85.45 | Strontium Sr = 87.63 | Yttrium Y = 89.0 | Zirconium Zr = 90.6 | Columbium Cb = 93.5 | Molybdenum Mo = 96.0 | — | Ruthenium Ru = 101.7 / Rhodium Rh = 102.9 / Palladium Pd = 106.7 |
| 7 | — | Silver Ag = 107.88 | Cadmium Cd = 112.40 | Indium In = 114.8 | Tin Sn = 119.0 | Antimony Sb = 120.2 | Tellurium Te = 127.5 | Iodine I = 126.92 | — |
| 8 | Xenon Xe = 130.2 | Cæsium Cs = 132.81 | Barium Ba = 137.37 | Lanthanum La = 139.0 | Cerium Ce = 140.25 | — | — | — | — |
| 9 | — | — | — | — | — | — | — | — | — |
| 10 | — | — | — | Ytterbium Yb = 172.0 | — | Tantalum Ta = 181.5 | Tungsten W = 184.0 | — | Osmium Os = 190.9 / Iridium Ir = 193.1 / Platinum Pt = 195.2 |
| 11 | — | Gold Au = 197.2 | Mercury Hg = 200.6 | Thallium Tl = 204.0 | Lead Pb = 207.10 | Bismuth Bi = 208.0 | — | — | — |
| 12 | Niton Nt = 222.4 | — | Radium Ra = 226.4 | — | Thorium Th = 232.4 | — | Uranium U = 238.5 | — | — |

which is commonly observed on this mineral. *Azurite* also has reference to color, namely a deep azure blue; *Vesuvianite* to Mount Vesuvius, where first found, and *tetrahedrite* to its crystallization in tetrahedrons. *Argentite* is so called because it is a compound of silver (argentum). *Magnesite* is a compound of magnesium. *Scheelite* is named after Scheele, a Swedish chemist, and *wollastonite* after Wollaston, an English scientist. It is thus seen that is some instances, outstanding physical or chemical properties have been incorporated in the names, whereas in other cases the minerals have been named after distinguished scientists or after the locality where first found.

FIG. 374.—Paul H. von Groth (1843 —). Professor of crystallography and mineralogy in the University of Munich. Eminent for his contributions on chemical and physical crystallography.

**Isomorphism.**—It can be easily shown that the various properties of minerals vary in general with the chemical composition. In order to emphasize this, it will be well to review briefly the periodic system of chemical elements. In 1869 the Russian chemist Mendeléeff published a classification of elements in which they were arranged in order of their increasing atomic weights. This classification is given on page 127. After certain intervals or periods, elements are observed which possess similar properties. For example, in group II calcium, strontium, and barium, are found directly under one another. These elements are extremely closely related to each other chemically. Obviously then, the carbonates of these three elements, $CaCO_3$, $SrCO_3$, and $BaCO_3$, will possess strikingly similar chemical properties. These carbonates occur in nature as the minerals aragonite, strontianite, and witherite, respectively. They all crystallize in the orthorhombic system.

The following tabulation gives the molecular weights, the specific gravities, several important angles, and the elements of crystallization of the minerals aragonite, strontianite, and witherite.

| Formula | Molecular weights | Specific gravity | Angles | | Elements of crystallization | | |
|---|---|---|---|---|---|---|---|
| | | | Prism | Dome | *a* | *b* | *c* |
| Aragonite $CaCO_3$..... | 100.0 | 2.9 | 63° 48′ | 71° 33′ | 0.6228 | : 1 : | 0.7204 |
| Strontianite $SrSO_3$..... | 147.6 | 3.7 | 62° 41′ | 71° 48′ | 0.6089 | : 1 : | 0.7237 |
| Witherite $BaCO_3$..... | 197.4 | 4.3 | 62° 12′ | 72° 16′ | 0.5949 | : 1 : | 0.7413 |

It is observed that the specific gravities increase regularly with the

molecular weights. The size of corresponding prism and dome angles on crystals of these three minerals is of the same character. A close examination, however, reveals small but regular differences. This is also true of the elements of crystallization. In both cases, nevertheless, the fact that the values, although among themselves slightly different, are of the same order, is at once noticed.

*Substances with analogous chemical compositions which crystallize in forms that are strikingly similar are said to be isomorphous.* Such substances may also crystallize together, that is, an analysis of strontianite will not infrequently show the presence of considerable calcium and barium replacing the strontium. Indeed, there are a number of instances where two chemical compounds may crystallize together in varying proportions. A striking illustration is the plagioclase series of feldspars in which albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$, are the end members. Between them are intermediate members whose composition and properties vary regularly from that of albite on the one hand to that of anorthite on the other. This is clearly shown by the following table:

| | |
|---|---|
| Albite, $NaAlSi_3O_8$ | (Ab) |
| Oligoclase, $Ab_3An_1$ | $Ab_3An_1$ |
| Andesine, $Ab_1An_1$ | $Ab_1An_1$ |
| Labradorite, $Ab_1An_3$ | $Ab_1An_3$ |
| Bytownite, $Ab_1An_3$ | An |
| Anorthite, $CaAl_2Si_2O_8$ | (An) |

Isomorphism is one of the most important principles in chemical mineralogy, for only in rare instances are minerals absolutely pure. Usually, as already indicated, one or more of the constituents have been replaced by others of analogous character. Thus, in the case of the garnet group, the general composition is best expressed by the formula $R''_3 R'''_2(SiO_4)_3$. In this formula, R'' may be either calcium, magnesium, ferrous iron, or manganese. R''' indicates ferric iron, aluminum, or chromium. Usually one of the elements in each of these groups predominates, the others being present in varying amounts. It is common practice to differentiate six distinct varieties of garnet depending upon the elements which predominate, as shown in the following table:

| | |
|---|---|
| Grossularite | $Ca_3Al_2(SiO_4)_3$ |
| Pyrope | $Mg_3Al_2(SiO_4)_3$ |
| Spessartite | $Mn_3Al_2(SiO_4)_3$ |
| Almandite | $Fe_3Al_2(SiO_4)_3$ |
| Uvarovite | $Ca_3Cr_2(SiO_4)_3$ |
| Andradite | $Ca_3Fe_2(SiO_4)_3$ |

Between these compositions there are all possible gradations, but in every instance the composition can be referred to general formula, $R''_3R'''_2(SiO_4)_3$.

**Dimorphism.**—Some chemical substances occur in different modifications with distinct physical and chemical properties. Thus, calcium carbonate is found in nature as the minerals calcite and aragonite. The following table gives the common characteristics of each.

| | Name | Crystallization | Specific gravity | Hardness | Optical Character |
|---|---|---|---|---|---|
| $CaCO_3$ | Calcite | Hexagonal | 2.7 | 3 | Uniaxial |
| | Aragonite | Orthorhombic | 2.9–3 | 3.5–4 | Biaxial |

When a chemical substance occurs in two distinct modifications, it is said to be *dimorphous;* in three modifications, *trimorphous;* in many, *polymorphous.* Among the minerals, carbon as the diamond and graphite, $FeS_2$ as pyrite and marcasite, and $KAlSi_3O_8$ as orthoclase and microcline are good examples of dimorphism. $TiO_2$ is trimorphous, for it occurs as the minerals rutile, brookite, and anatase. The element sulphur is an excellent example of a polymorphous substance having at least six modifications.

**Isodimorphism.**—The various members of an isomorphous series may each be dimorphous. This is illustrated by the following isodimorphous series.

| Cubic modification | Compound | Orthorhombic modification |
|---|---|---|
| Pyrite | $FeS_2$ | Marcasite |
| Smaltite | $CoAs_2$ | Safflorite |
| Chloanthite | $NiAs_2$ | Rammelsbergite |

If this series is studied vertically the members are seen to be isomorphous, and when considered horizontally they are dimorphous.

## CHAPTER XII

## FORMATION AND OCCURRENCE OF MINERALS

In general minerals may have been formed in four ways:

1. From solution.
2. From fusion.
3. By sublimation.
4. By metamorphism.

Of these methods, formation from solution and fusion are the most important. Most of the best crystals observed on minerals are the result of solidification from solution.

### FORMATION FROM SOLUTION

Minerals may form from solution in various ways. The following are some of the most important methods.

(*a*) *Evaporation of the Solvent.*—Gypsum and halite are commonly the result of the simple evaporation of the solution in which they were dissolved. In many instances these deposits are of great thickness. This is especially true of those occurring in central New York, Michigan, Kansas, and Iowa. Many minerals have been formed in this way.

(*b*) *Loss of Gases Acting as Solvents.*—When water containing a considerable amount of carbon dioxide in solution comes in contact with limestone, calcium carbonate readily passes into solution as the acid or bicarbonate ($CaH_2(CO_3)_2$). This is, however, an unstable compound and due to various factors, the carbon dioxide in solution may be lost causing the bicarbonate to revert to the insoluble normal carbonate ($CaCO_3$), which is at once deposited. In limestone districts calcium carbonate is thus frequently dissolved in large quantities and subsequently deposited in caves in the form of *stalactites*, suspended from the roof, or as *stalagmites*, found upon the floor of the caves. It is also frequently deposited in this way around springs and in the beds of the streams resulting from them. Here it is generally observed as moss-like deposits, often enclosing twigs and leaves, and is called *calcareous tufa* or *travertine*. By virtue of the presence of carbon dioxide, calcium carbonate passed into solution but was later deposited when the carbon dioxide escaped.

(*c*) *Change of Temperature and Pressure.*—In regions of geysers and hot springs the solubility of the circulating water is commonly greatly increased because of its high temperature and the pressure to which it is

subjected. These waters therefore frequently contain much more mineral matter in solution than can be retained after they reach the surface, where the temperature is lowered and the pressure reduced. In these localities considerable quantities of silicious sinter or geyserite are observed, which have formed in this way.

(*d*) *Interaction of Solutions.*—As is commonly observed in the chemical laboratory, two solutions may interact and form an insoluble compound which is at once precipitated or deposited. Thus, a solution of calcium sulphate ($CaSO_4$) when brought into contact with one of a soluble barium compound such as, $BaCl_2$, yields at once the insoluble barium sulphate ($BaSO_4$). When found in nature, barium sulphate is called *barite.* This mineral has undoubtedly been frequently formed in this way.

(*e*) *Interaction of Solutions and Solids.*—A solution containing lead and sulphur ions may interact with limestone and yield galena (PbS), calcite or calcium carbonate having passing into solution. Thus, galena replaces the calcite of the limestone. This process is often called *replacement* or *metasomatism.* In the same way the interaction of a solution of zinc sulphate with limestone may cause the formaton of smithsonite ($ZnCO_3$) and calcium sulphate. Metasomatism has often been of great importance in the formation of valuable ore deposits.

(*f*) *Interaction of Gases with Solutions.*—Waters charged with hydrogen sulphide precipitate sulphides from mine and quarry waters containing copper or iron. Presumably, many of the sulphide minerals have thus been formed.

(*g*) *Action of Organisms upon Solutions.*—Mollusks, corals, crinoids, and other organisms secrete calcium carbonate from ocean water in the formation of shells and the hard parts of their bodies. This calcium carbonate may be either in the form of calcite or aragonite. Sponges, radiolaria, and diatoms similarly secrete silica. Diatomaceous earth, chert, and other forms of chalcedony may be formed in this manner. Limonite and sulphur may result from the action of certain bacteria upon water containing iron or sulphates in solution. Algæ may cause the deposition of gyserite from the water of hot springs. The large deposits of soda niter in Chile are thought by some to be the result of the action of organisms.

## FUSION

The minerals composing the igneous rocks are the result of solidification from a molten mass called the *magma.* Only rarely, however, does such a molten mass contain the constituents of a single mineral, so that generally several minerals are formed on cooling. In reality solidification takes place from a solution possessing a very high temperature,

and obviously good crystals can only result if the process of cooling is comparatively slow. Hence, some portion of the molten or fused mass is apt to form amorphous and glassy material. Water and other active mineralizers are frequently contained in the magma and are of great importance in determining the character and size of the resulting minerals. Such igneous rocks as granite, syenite, diorite, and basalt, for example, are composed of minerals formed in this way. For a further description of the character and composition of such rocks, see pages 137 and 143.

### SUBLIMATION

Under this heading are included not only the minerals, which are the result of having passed from a solid state through the vapor and back to the solid state again, but also those which are the result of the interaction of gases upon another and upon the country rock. Halite (NaCl) and sal-ammoniac ($NH_4Cl$) are sometimes the result of simple sublimation. In the vicinity of volcanoes small scales of hematite ($Fe_2O_3$) are frequently found in the cavities of lava, resulting from the interaction of volatile $FeCl_3$ and water vapor. Thus, $2FeCl_3 + 3H_2O = Fe_2O_3 + 6HCl$.

Among the important volatile mineralizers, mention may be made of water vapor, which usually predominates, chlorine, boron, fluorine, and some of their compounds. Minerals formed in this way are usually said to be the result of *pneumatolytic action* or *pneumatolysis*. One of the most prominent examples of this character is the formation of cassiterite ($SnO_2$), which is frequently associated with fluorite ($CaF_2$).

$$SnF_4 + 2H_2O = \underset{\text{(Cassiterite)}}{SnO_2} + 4HF$$

$$4HF + \underset{\substack{\text{(Limestone}\\\text{or calcite)}}}{2CaCO_3} = \underset{\text{(Fluorite)}}{2CaF_2} + 2H_2O + 2CO_2$$

In this case, it is assumed that volatile $SnF_4$ and water vapor interact and form $SnO_2$ (cassiterite) and hydrofluoric acid. The latter, however, is an exceedingly active chemical compound and hence tends to react with whatever it comes in contact, which in the above reaction is supposed to be limestone or the calcite of the adjacent rock. Fluorite is thus formed as the result of this reaction.

The following minerals are frequently regarded as being the result of pneumatolytic action: tourmaline, fluorite, cassiterite, topaz, scapolite, and phlogopite.

### METAMORPHISM

Under the influence of certain processes involving principally heat, moisture, pressure, and the presence of alkaline substances, profound changes in the character, structure, and mineral constituents of rocks

are frequently wrought. In this way sedimentary and igneous rocks may be changed. When such changes are limited in extent, the results constitute what is commonly called *local or contact metamorphism.* This type of metamorphism is most pronounced in the vicinity of dikes, intrusive sheets, and lava streams, that is, wherever older rocks, especially limestones and shales, have been subjected to the action of magmas. Similar changes may, however, take place over large areas, due to what are generally known as mountain-making processes. Such changes generally are the result of *regional metamorphism.*

*a. Local or Contact Metamorphism.*—A considerable number of minerals are commonly the result of contact metamorphism. Wollastonite, garnet, graphite, calcite, and diopside are frequently formed when impure limestone is metamorphosed by contact action. If considerable amounts of magnesium are present tremolite, spinel, phlogopite, chondrodite, and olivine may be formed in addition to calcite and dolomite.

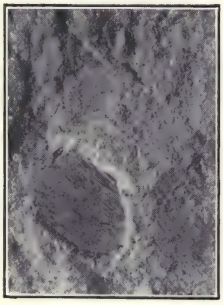


FIG. 375.—Disseminated crystals of orthoclase in trachyte.

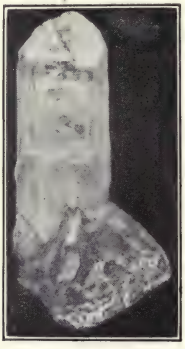


FIG. 376.—Attached crystal of quartz.

*b. Regional Metamorphism.*—Here large areas have been affected, and the structure of the rocks may be profoundly changed. This type of metamorphism is, however, not as productive of new minerals as is local or contact metamorphism. By regional metamorphism, soft or bituminous coal has been changed to hard or anthracite coal, sedimentary limestone to marble, and igneous granite to a gneiss. Sandstone is converted into quartzite and shale into slate.

## OCCURRENCE OF MINERALS

Minerals may be found either *disseminated* throughout other minerals or rocks (Fig. 375) or they may occur *attached* as crystals (Fig. 376) or adhering as crusts or in layers on other minerals or rocks. When found disseminated they sometimes exhibit crystal forms, although

they are most frequently observed in irregular particles or grains. Disseminated crystals are generally *doubly or fully terminated.* Crusts of compact calcite so commonly observed coating the exposed surfaces of limestone in cracks or coating pebbles in stream beds are illustrative of

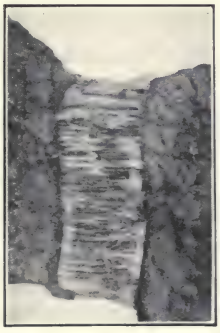


FIG. 377.—Vein of serpentine.

FIG. 378.—Banded vein of sphalerite (dark), fluorite, and calcite.

the attached occurrence. Under favorable conditions crystals frequently form with one end well developed and the other adhering to the rock or mineral on which it was formed. Attached crystals are generally only *singly terminated* (Fig. 376).

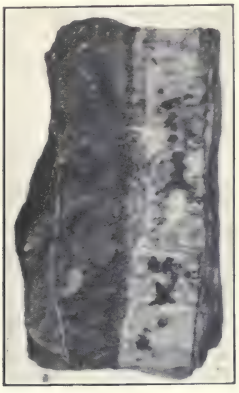


FIG. 379.—Quartz vein with copper (dark).

FIG. 380.—Vein of smaltite and calcite (light).

Cracks or crevices filled with mineral matter, are spoken of as *veins,* (Fig. 377). When a vein consists of several minerals deposited in layers or bands, it is termed a *banded vein,* (Fig. 378). Veins may be *symmetrically* or *unsymmetrically banded,* depending upon whether or not the same minerals are encountered in passing from opposite walls

of the vein to the center of it. The character of veins, as to their width and constituents, varies greatly in different localities. In some instances the width and mineral contents will continue practically unchanged over considerable distances laterally and vertically, whereas in other cases marked changes take place (Figs. 379 and 380). When a vein consists principally of unimportant or valueless material, which however contains some mineral of value disseminated throughout it, the former is spoken of as the *gangue*. Thus, in a gold-bearing quartz vein, quartz is obviously the gangue mineral, also see Figs. 379 and 380.

Veins have been formed principally as the result of solidification of mineral matter from solution. These solutions may have been descending or ascending in character, while in some instances their flow may have been largely lateral. Where veins trending in different directions cross, due to a possible difference in the character of the solutions from which they were formed, mineralization is usually most pronounced. In

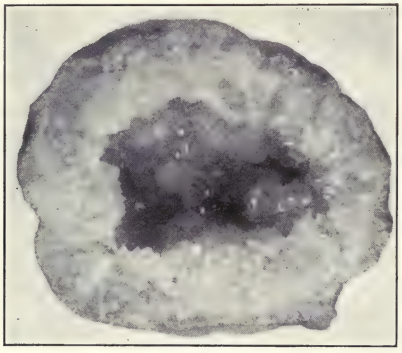


FIG. 381.—Quartz geode.

fact, it is well known that the richest mineral deposits, or what are frequently called *bonanza ores*, are to be expected at the intersection of veins.

*Geodes* are cavities lined with mineral matter, which frequently consist of well-developed crystals. Quartz and calcite geodes are not uncommon (Fig. 381). Some geodes are large enough to be designated as caves. Thus, the "crystal" cave on the island of Put-in-Bay in Lake Erie is a huge geode containing crystals of celestite ($SrSO_4$). Similarly, large geodes lined with quartz crystals are found in the Alps of Switzerland.

When crystals or minerals are found in the places they were formed, we may speak of them as occurring *in situ*. They are also said to be found in the parent or mother rock. When found in the sands and gravels of streams or of other bodies of water, as the result of transportation, they are said to occur in *secondary deposits* or *placers*. When gold is found in a quartz vein, it may be said to be observed *in situ*, but when it is

recovered from the sands and gravels of a stream or lake, we refer to it as *placer* gold. There are also platinum, diamond, and cassiterite placers.

## ROCKS

As was indicated on page xii, the earth's crust consists of solid material, commonly called rocks, and as these are composed of minerals, it is obvious that rocks must be the source of most minerals. A brief description of the most common and important rocks will therefore be given.

Any mineral or aggregate of minerals comprising an important part of the earth's crust may be termed a *rock*. A rock may consist of a single component as, for example, a sandstone or limestone, see page xii. In the majority of rocks, however, two or more minerals are present as is illustrated in the case of the granite where the three principal constituents are quartz, orthoclase, and mica or hornblende. To illustrate the relationship between minerals and rocks, the minerals might be compared to the letters of the alphabet and the rocks to the words.

Depending upon origin three main groups of rocks may be differentiated. The *igneous* rocks are those which have resulted from the solidification of a molten mass, commonly called a magma. The *sedimentary* rocks, on the other hand, were deposited in water, either as fragments carried mechanically or as chemical precipitates, while the *metamorphic* rocks were developed from either the igneous or sedimentary types by geological forces including heat, pressure, and circulating waters.

### Igneous Rocks

If the magma be permitted to cool slowly it will in time become supersaturated with reference to certain chemical compounds which then separate or crystallize out to form the various minerals. The important rock-forming minerals of igneous rocks comprise (*a*) the *essential* and (*b*) the *accessory* minerals. The former are those whose presence have a direct influence upon the character and name of the rock. This division would include the feldspars, pyroxenes, amphiboles, micas, nephelite, leucite, olivine, and quartz. The accessory minerals, as the name indicates, are those present in smaller amounts. They do not affect appreciably the character of the rock. The more important ones would include magnetite, ilmenite, pyrite, pyrrhotite, apatite, zircon, and titanite.

The order of crystallization from the magma, while not constant in all cases, tends to proceed in a more or less definite manner. The accessory minerals being the first to form, usually show very good crystal outlines. The ferro-magnesium minerals (biotite, hornblende, or augite)

follow the accessory constituents and these in turn are followed by the feldspars. If the original magma contained a large amount of silica, the excess, if any remains after combining to form the above mentioned minerals, separates out as quartz. From this sequence it will be seen that the more basic minerals—those low in silica—crystallize out first to be followed by those more acid in composition.

Those igneous rocks which are the result of magmas that have reached the surface are termed *extrusive* or *volcanic*. Due to the escape of dissolved gases and the rapid rate of cooling, rocks of this type are characterized by glassy, cellular, or extremely fine grained (felsitic) textures. Magmas, on the other hand, that have solidified at depths produce rocks that are spoken of as *plutonic* or *intrusive*. These have cooled very slowly and consequently possess larger and better developed crystal grains. They are said to have a granular texture. In many instances the texture of an intrusive rock is sufficiently coarse to permit of the identification of all the essential minerals with the naked eye.

FIG. 382.—Auguste Michel-Levy (1844–1911). For many years professor in the College de France, Paris. Distinguished for his researches on rock-forming and synthetic minerals.

The field classification of igneous rocks is based primarily upon grain or texture and mineral composition. The latter depends, however, upon the chemical composition of the original magma. Magmas containing 65 to 80 per cent. of $SiO_2$ will produce acid or light colored rocks. In these there is developed an abundance of orthoclase, some quartz, and a subordinate amount of ferro-magnesium minerals. Examples of this type are granite, rhyolite, aplite, and pegmatite. The basic or dark colored rocks result from magmas containing less than 52 per cent. of $SiO_2$. In these we have an excess of the ferro-magnesium minerals, some feldspar (plagioclase), and olivine, but no quartz. Gabbro, peridotite, pyroxenite, and basalt are a few examples of basic rocks. The intermediate types must then result from those magmas whose $SiO_2$ content is somewhere between 65 and 52 per cent. and are represented by syenite, diorite, trachyte, and andesite. A summary of some of the more important igneous rocks is given in the following table. It should be noted, however, that in nature rocks grade gradually from one type into another, and do not show the sharp distinctions inferred from the rulings in the diagram.

From an inspection of the chart it will be seen that a rock with a granular texture is called a granite when it contains orthoclase, a dark constituent, and quartz, while a rock with the same texture without

| | Orthoclase acid ← | | Plagioclase intermediate → | | Feldspar-free basic | |
|---|---|---|---|---|---|---|
| Dark constituent | Mica or hornblende | | Hornblende or augite | | Augite or hornblende | |
| Distinguishing mineral | + Quartz | − Quartz | − Quartz | ± Olivine | − Olivine | + Olivine |
| Granular texture | Granite | Syenite | Diorite | Gabbro Dolerite | Pyroxenite | Peridotite |
| Felsitic texture | Rhyolite | Trachyte Felsite | Andesite | Basalt | Augitite | Limburgite |
| Glassy texture | Obsidian Pitchstone | | Tachylyte (Basaltic glass) | | | |
| Cellular texture | Pumice | | Scoria | | | |

the quartz is known as a syenite. Rhyolite and trachyte are mineralogically the equivalents of granite and syenite but possess a felsitic rather than granular texture. Diorite, on the other hand, is a granular rock consisting essentially of plagioclase and hornblende, while gabbro contains plagioclase, augite, and frequently some olivine. The term *dolerite* may be employed for those types of diorite-gabbro rocks where it is impossible to determine with the naked eye whether the dark constituent is hornblende or augite. Andesite and basalt are the felsitic equivalents of diorite and gabbro, respectively.

*Dike Rocks.*—Frequently penetrating the larger rock bodies will be found fissures containing intrusions of igneous material. These occurrences are known as dikes. They are of later origin than the rock penetrated and may be either extremely acid or very basic in character. The acid or light colored dikes include *aplite* and *pegmatite*, while the general term *lamprophyre* has been suggested for all the basic types. Aplite is an extremely fine and even-grained rock consisting largely of quartz and orthoclase with a very subordinate amount of dark material. Pegmatite, while possessing in general the same mineral composition as the aplite, has, on the contrary, an exceedingly coarse and uneven texture. In the formation of pegmatites it is believed that mineralizers have played an important rôle. The dissolved vapors would not only increase the fluidity of the magma, thus reducing internal friction, and permit the growth of crystals of unusual size, but also explain the size and concentration of accessory minerals which are so abundant in some pegmatites. A list of a few of the more common accessory minerals would include tourmaline, beryl, topaz, fluorite, spodumene, wolframite, and columbite. The basic dikes are not so well crystallized nor do they, as a rule, contain the wealth of accessory minerals which characterizes the acid types.

## Sedimentary Rocks

These are all of secondary origin having been derived from the disintegration of older rocks through the action of agencies included under the comprehensive term of "weathering." That portion of the mineral matter which is carried away in solution may at some later period be deposited either through strictly chemical action, by slow evaporation, or through processes involving organic life.

Sedimentary rocks are characterized by a parallel or bedded structure in which the nature of the material composing the layers varies in thickness, composition, and color or size of the individual grains. They form widely extended deposits which, generally speaking, are without great vertical dimensions, especially when compared with some of the massive igneous formations. A field classification based on origin would divide the sedimentary rocks into three main groups, (*a*) the *mechanical*, (*b*) the *chemical* and (*c*) the *organic sediments*. The mechanical sediments would include shale, sandstone, conglomerate, and breccia. While the formations of anhydrite, gypsum, and salt would be classified as chemical deposits. Those of organic origin would include coal, limestone, and dolomite.

*Shale.*—The finest particles carried mechanically by the water, and generally referred to as mud or silt, when reaching the sea, settle quickly due to the action of the soluble salts in the ocean water. These deposits, when consolidated, yield a very fine and even-grained rock—possessing a good parting parallel to the bedding—which is known as *shale*. The chief mineral components are kaolinite, quartz, and feldspar, although these constituents cannot be distinguished with the naked eye. As the amount of quartz and size of the grain increases the shale gradually passes over into a sandstone. The colors of shale may vary from green to gray and in some instances may even be black (*carbonaceous shale*). In some of the shales of northwestern Colorado and adjacent States oil has been detected and in several instances the amount has reached forty to fifty gallons per ton of rock. These are termed *oil shales*. The oil can be obtained by distillation at a low temperature and paraffine wax and ammonium sulphate recovered from the residue.

*Sandstone.*—When particles of sand of nearly uniform size become consolidated a sandstone results. The individual components are usually rounded and consist essentially of quartz. When considerable feldspar is present the rock is spoken of as feldspathic sandstone or *arkose*. The cementing material varies greatly both in amount and character. In some instances it is silica, although calcium carbonate, clay, or iron oxide may serve as the binding material. The most durable sandstones for structural purposes are those with a silicious cement. Those containing iron oxide show, however, the greatest variation in color. A thinly

bedded argillaceous sandstone is called a *flagstone*, while the term *freestone* is applied to those homogeneous types which occur in thick beds and can be worked in all directions with equal ease. A *conglomerate* is a rock term applied to rounded, water worn pebbles of various sizes which are held in a matrix of finer materials. If the fragments are sharp and angular instead of rounded the term *breccia* is employed. Breccias are quite common in limestone regions where the movement along a fault plane has crushed the rock to various degrees of fineness. These are known as *friction breccias* in contrast to *volcanic breccias* which are composed of consolidated, angular fragments of igneous material.

*Limestone and Dolomite.*—A limestone is a sedimentary rock consisting essentially of calcium carbonate with minor amounts of magnesium carbonate, silica, clay, iron oxide, or carbonaceous material. The majority of limestones were formed by organisms such as brachipods, corals, molluscs, and crinoids, which have secreted calcium carbonate taken from the waters and utilized the material to form shells and skeletons. The pressure of superimposed rocks has, in many instances, largely destroyed its original fossiliferous character. The variety known as *oölitic limestone* is composed of small rounded grains of concretionary nature. With an increase in the content of magnesium carbonate, the limestone gradually passes over to a dolomitic limestone and finally to a *normal dolomite*, which theoretically contains 54.35 per cent. $CaCO_3$ and 45.65 per cent. $MgCO_3$. Normal dolomite is both slightly heavier and harder than the limestone and will not effervesce so freely when treated with cold, dilute acids. Many dolomites are believed to be the result of magnesium solutions reacting upon limestones as indicated by the equation: $2\,CaCO_3 + MgCl_2 = CaMg(CO_3)_2 + CaCl_2$.

### Metamorphic Rocks

The compressive force due to contraction of the earth, together with heat, caused by folding and crushing of the rock strata, and the chemical action of liquids produce profound changes in both igneous and sedimentary rocks. The alterations noted are either mineralogical or chemical in character and frequently also include a change in the original texture. The resultant rocks, classified as metamorphic, possess certain features which resemble both the igneous and sedimentary types. They are crystalline in character and in this respect are similar to the igneous rocks. Many, on the other hand, possess a banded structure caused by minerals of like character being brought together in parallel layers. This parallel arrangement is termed *schistose structure*. Some of the important types referred to the action of regional metamorphism (page 134) include gneiss, schists, quartzite, slate, and marble.

*Gneiss.*—This is a laminated rock which generally has the mineral

composition of the granite. The intermingled grains of quartz and feldspar are separated by layers of the dark constituent. The banding may extend in straight parallel lines or be curved and bent. Gneisses differ from schists in that they are more coarsely laminated and contain the mineral feldspar. They usually represent an altered igneous rock as the granite, although they may also have originated from a coarse feldspathic sandstone or conglomerate. Gneisses are of widespread occurrence, especially in the older geological formations.

*Schists.*—These are laminated metamorphic rocks which split readily along planes that are approximately parallel. Depending upon the character of the prevailing mineral, four types are easily differentiated, namely, the mica, chlorite, talc, and hornblende schists. In the mica schist the scales are so arranged that the cleavage directions are all parallel, thus producing a rock of pronounced schistose structure. In addition to mica, more or less quartz, also well developed crystals of garnet, cyanite, and staurolite are frequently present. Next to the gneiss, the mica schist is the most abundant metamorphic rock. Usually it is the result of the alteration of a fine grained sedimentary deposit, as clay or shale. In chlorite schist the chief component is the green, granular, or scaly mineral chlorite. In many instances it has been formed from some basic igneous rock such as gabbro or basalt. In the case of talc schist the predominating mineral is talc which gives the rock a characteristic soapy feel. As talc is a magnesium silicate it can only be developed from the feldspar free rocks, or if of sedimentary origin, from impure dolomites. A schist consisting largely of black slender prisms of hornblende is termed a *hornblende schist.* As the needles are all arranged with their long direction parallel to the schistosity, these schists cleave readily and show a marked silky luster.

*Quartzite.*—This is a very firm compact rock containing quartz grains with a silicious cement. It is the result of the intense metamorphism of a sandstone. In an ordinary sandstone it will be seen that the fracture always follows the cement, while in a quartzite it passes through grains and cement alike.

*Slate.*—This is an exceedingly fine grained rock which breaks very easily in thin broad sheets. The cleavage, as a rule, does not correspond to the bedding planes of the shale from which most slates were derived, but cuts these planes at various angles. In mineral composition the slates consist of quartz and mica with subordinate amounts of chlorite, hematite, or graphite, which contribute the green, red, and black colors, respectively. Slates containing a considerable amount of iron carbonate have a tendency to discolor on exposure and are termed *fading slates* in the building trade.

*Marble.*—Strictly speaking, the term marble includes limestones or dolomites which have been recrystallized and are capable of taking a

polish. The term, however, is used somewhat loosely and not infrequently includes any limestone that will take a polish irrespective of its crystalline character. Scales of mica arranged in wavy streaks or bands are frequently present which add to the attractiveness of the stone, but interfere with the continuity of the polish and lower its resistance to atmospheric agencies when placed in exposed positions. Marbles show great variation in texture and color. Statuary marbles demand the purest and whitest varieties, while ornamental types show strongly contrasted color effects. For structural purposes uniformity of color is essential. Marbles are not so widely distributed as limestones and are confined almost entirely to metamorphic areas.

## DECOMPOSITION AND WEATHERING OF MINERALS

As soon as minerals are formed and are exposed to atmospheric conditions, they are subject to change. By the action of moisture, the oxygen of the air, humus acids of the soil, and other agencies profound changes are brought about. In some cases the alteration takes place rather rapidly while in others it may proceed very slowly. All minerals are, however, sooner or later acted upon. The changes are effected by the action of processes familiar to students of chemistry. Some of the more important are: solution, oxidation, reduction, hydration, and carbonatization. In most instances several of these processes may have been effective simultaneously or successively.

## PSEUDOMORPHS

Not infrequently minerals alter in such a way that the structure of the original specimen is retained. For example, limonite ($Fe_2O_3.H_2O$) is sometimes found as crystals which were originally pyrite ($FeS_2$). That is, by means of oxidation and hydration pyrite has been altered to limonite without destroying the crystal form. Such crystals are called *pseudomorphs*, and in the case, just referrred, they are known as pseudomorphs of *limonite after pyrite*. There are several interesting types of pseudomorphs.

**Paramorphs.**—In these a molecular rearrangement has taken place, without the chemical composition being changed. Paramorphs are possible only in the case of polymorphous substances. Thus, rutile ($TiO_2$), tetragonal, after brookite ($TiO_2$), orthorhombic. Also, calcite ($CaCO_3$), hexagonal, after aragonite ($CaCO_3$), orthorhombic.

**Alteration Pseudomorphs.**—The change in composition may involve the loss of some constituents, the addition of new ones, or there may be a partial exchange. Anhydrite ($CaSO_4$) after gypsum ($CaSO_4.2H_2O$), malachite ($CuCO_3.Cu(OH)_2$) after cuprite ($Cu_2O$), and kaolin ($H_4Al_2Si_2O_9$)

after orthoclase ($KAlSi_3O_8$) are excellent illustrations of pseudomorphs of this type.

**Substitution Pseudomorphs.**—Sometimes the replacing mineral has no chemical relation to the original substance. Good illustrations are the pseudomorphs of quartz ($SiO_2$) after fluorite ($CaF_2$), and quartz after calcite ($CaCO_3$).

**Incrustation Pseudomorphs.**—At times a mineral may be deposited upon the crystal form of another and completely enclose it. Thus, smithsonite ($ZnCO_3$) after calcite ($CaCO_3$) (Fig. 520, page 247). Incrustation pseudomorphs of quartz after fluorite are sometimes of such a character as to permit the deposit of quartz with the cubical casts of fluorite to be removed intact

## CHAPTER XIII

## QUALITATIVE BLOWPIPE METHODS

Whenever possible it is advisable to determine minerals at sight, that is, by means of their physical properties, occurrences, and associates. It frequently becomes necessary, however, to supplement these observations by simple, confirmatory, chemical tests. These reactions, obtained largely at high temperatures by the proper use of the blowpipe, are referred to as blowpipe reactions. The chemist in his laboratory can increase the number of his reagents at will and naturally his field of operation is larger than that of the student equipped with a blowpipe, who relies upon a limited number of reagents and the effects produced when minerals are subjected to the oxidizing or reducing action of a flame. The ease with which many of the blowpipe tests are obtained and the small amount of apparatus and reagents required have made these reactions popular with both the mineralogist and geologist.

The equipment which is necessary may be limited to the following apparatus and reagents.

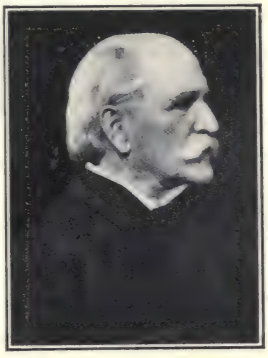


FIG. 383.—George J. Brush (1831–1912). For many years a professor in Yale University. Distinguished for the application of blowpipe and chemical methods in the determination of minerals.

### APPARATUS

*Blowpipe.*—The best type consists of a brass or nickel plated, slightly conical shaped tube *a* (Fig. 384) about 18 cm. in length, into the larger end of which fits a mouth piece of hardened rubber *b*. At the opposite end a hollow, cylindrical chamber *c*, serves to collect the moisture which condenses in the tube. A side tube, *d*, joins the air chamber at right angles and is equipped with a platinum tip *e*, in the center of which is a smooth hole from 0.4 to 0.6 mm. in diameter.

*Lamps.*—Where illuminating gas is available, the most convenient form of lamp is the Bunsen burner equipped with an additional inner tube which is flattened at the upper end and cut off obliquely (Fig. 385). The supply of gas should be so regulated that a luminous flame about 4 cm. in height results. Where gas is not available lamps may be secured which burn either liquid (alcohol, olive oil, lard oil) or solid (tallow, paraffin) fuel. By the addition of a small amount of turpentine

to the alcohol the luminosity as well as the reducing power of the flame is greatly increased. A candle flame may also be used to advantage.

*Forceps.*—Plain iron, or better still platinum tipped, forceps are indispensable for testing the fusibility of minerals as well as for noting flame colorations.

*Charcoal.*—Rectangular blocks of charcoal about 10 × 2½ × 2½ cm. are useful supports during the fusion of the assay. Likewise films are often condensed and deposited on the cooler portion of the support. Charcoal made from willow, pine, or basswood is usually recommended.

*Plaster Tablets.*—These are made by preparing a thin paste of plaster of Paris and water, and spreading it over an oiled glass plate until a uniform thickness of about 5 mm. is secured. Before the plaster has hardened the surface is ruled by a knife into rectangular divisions 10 cm. long and about 5 cm. wide. These tablets are especially well adapted for the condensation of iodide sublimates.

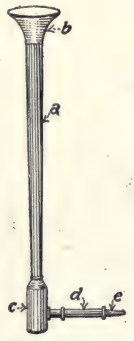



FIG. 384.—Blowpipe.

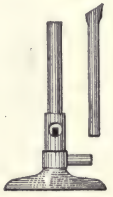


FIG. 385.—Bunsen burner with inner tube.

*Platinum Wire.*—No suitable substitute has been found to replace platinum wire for flame colorations and bead tests. The wire should be No. 27 or 28 B. & S. gauge, about 10 cm. long. One end should be fused into a piece of glass tubing.

*Hammer and Anvil.*—A small hammer weighing about 75 g. with a wire handle is recommended. Also a block of steel 4 cm. square and 1 cm. thick, for crushing material to be tested.

*Agate Mortar and Pestle.*—The mortar should be at least 4 cm. in diameter. It is used for pulverizing material.

*Diamond Mortar.*—The mortar should be of tool-steel, about 4 cm. square and possess a cylindrical cavity to receive the pestle. It is indispensable in crushing minerals to a fairly fine powder.

*Open and Closed Tubes.*—Hard glass tubing, 12–14 cm. in length and about 5 mm. inside diameter, is employed either open at both ends to note the effect of a current of heated air upon the mineral, or closed at one end for the detection of volatile acids.

*Merwin Flame-color Screen.*—This is a celluloid screen, 7½ × 12½ cm., consisting of three colored strips, one blue, one violet, and one blue over violet. The strips are so stained as to absorb the orange and yellow portions of the spectrum. This screen is extremely useful in the examination of flame colorations and is far superior to the "blue" and "green glass" formerly employed for the same purpose.

Other articles for blowpipe work which need no detailed description are the following:

*Test-tubes.*—12 cm. in length and 15 mm. in diameter.

*Test-tube Stand, Test-tube Brush and Holder.*

*Magnet.*—Horseshoe type.

*Watch-glasses.*—5 cm. in diameter.

*Glass Funnel and Filter Paper.*—Bunsen rapid filtering funnel 65 mm. in diameter.

*File.*—Triangular for cutting glass tubing.

*Pliers.*—Serviceable in breaking and cutting fragments of minerals.

Figure 386 shows an assembly of the above apparatus.

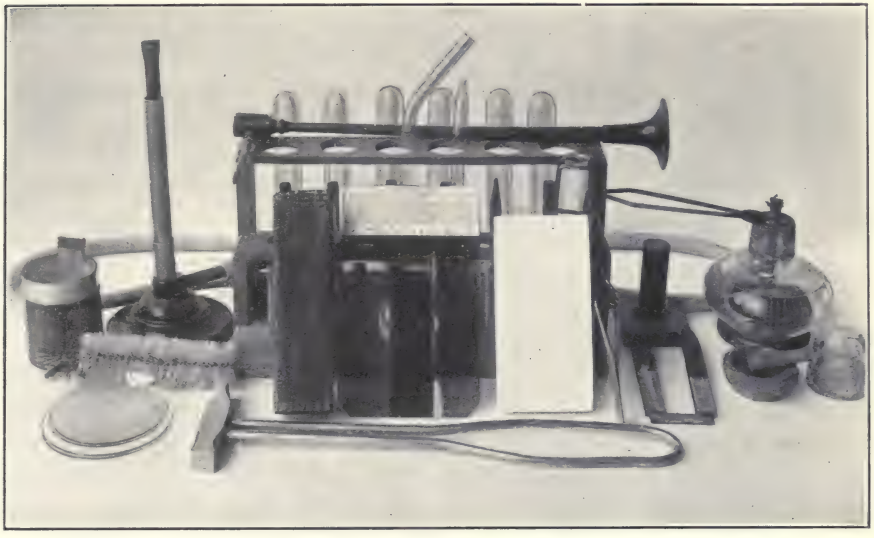


FIG. 386.—Assembly of apparatus frequently used in blowpipe methods.

## DRY REAGENTS

These reagents should be kept in wide mouthed glass bottles.

*Sodium Carbonate,* $Na_2CO_3$; or *Sodium Bicarbonate,* $NaHCO_3$. Employed extensively in the decomposition of minerals.

*Borax,* $Na_2B_4O_7.10H_2O$. When fused in a loop of platinum wire it is used for bead tests. Borax glass is fused and pulverized borax.

*Microcosmic Salt or Salt of Phosphorus,* $HNaNH_4PO_4.4H_2O$. Also used for bead tests. Upon heating, water and ammonia are liberated and the salt is transformed to sodium metaphosphate, $NaPO_3$.

*Test-papers.*—Blue and red litmus for alkaline and acid reactions. Yellow turmeric paper for the detection of boracic acid and zirconium.

*Potassium Bisulphate,* $KHSO_4$. Used in fusions for decomposing minerals.

*Bismuth Flux.*—An intimate mixture of one part by weight of KI,

one part of $KHSO_4$, and two parts of S. When used on the plaster support many elements yield highly colored iodide sublimates.

*Boracic Acid Flux.*—Consists of three parts of finely pulverized $KHSO_4$ and one part of powdered fluorite ($CaF_2$). Employed for the detection of boron in silicates.

*Potassium Nitrate,* $KNO_3$. When used with a fusion mixture it accelerates oxidation.

*Granulated Tin and Zinc.*—Used in acid solutions to affect reduction.

*Magnesium Ribbon.*—For the detection of phosphoric acid.

## LIQUID REAGENTS

Work in the field demands that the number of reagents, and especially those of the liquid type, be reduced to a minimum. Under these conditions it is possible to restrict the number of wet reagents to ammonia, a 10 per cent. solution of cobalt nitrate, and the common acids, HCl, $HNO_3$, and $H_2SO_4$. In the laboratory it is far better to augment this number in order to materially extend the range of operations.

*Alcohol.*—95 per cent. ethyl alcohol.

*Ammonium Hydroxide,* $NH_4OH$. One part of the concentrated alkali diluted with two parts of water.

*Ammonium Molybdate,* $(NH_4)_2MoO_4$. Dissolve 50 g. of $MoO_3$ in a mixture of 200 cc. water and 40 cc. $NH_4OH$ (sp. gr. 0.90). The solution should be kept warm. The liquid is then filtered and poured with constant stirring into a mixture of 200 cc. $HNO_3$ acid (sp. gr. 1.42) and 300 cc. of water.

*Ammonium Oxalate,* $(NH_4)_2C_2O_4.2H_2O$. 20 g. dissolved in 500 cc. of water.

*Barium Chloride,* $BaCl_2.2H_2O$. 30½ g. dissolved in 500 cc. of water.

*Calcium Hydroxide,* (Lime Water), $Ca(OH)_2$. Prepared by shaking CaO with water and decanting the clear liquid.

*Cobalt Nitrate,* $CO(NO_3)_2.6H_2O$. One part of the crystallized salt is dissolved in 10 parts of water and the solution kept in dropping bottles.

*Dimethylglyoxime,* $C_4H_8O_2N_2$. Prepare a saturated solution in 50 per cent. alcohol to which a small amount of ammonia has been added.

*Di-sodium Hydrogen Phosphate* (Sodium Phosphate), $Na_2HPO_4.12H_2O$. 30 g. dissolved in 500 cc. of water.

*Ferrous Sulphate,* $FeSO_4.7H_2O$. Solution prepared as needed.

*Hydrobromic Acid,* HBr. Prepared by passing $H_2S$ through a solution of bromine in water until the red color of the liquid bromine disappears. The flask should be cooled with running water while being charged.

*Hydrochloric Acid,* HCl. The C.P. concentrated acid is diluted with an equal volume of water.

*Hydrogen Peroxide,* $H_2O_2$. 3 per cent. solution.

*Lead Acetate,* $Pb(C_2H_3O_2)_2.3H_2O$. 47½ g. dissolved in 500 cc. of water.

*Nitric Acid,* $HNO_3$. Used either in its concentrated form or one part of the acid is diluted with two parts of water.

*Nitrohydrochloric Acid* (Aqua Regia). A mixture of 3 parts of concentrated HCl acid and 1 part of concentrated $HNO_3$ acid.

*Potassium Ferricyanide,* $K_3Fe(CN)_6$. 27½ g. dissolved in 500 cc. of water.

*Potassium Ferrocyanide,* $K_4Fe(CN)_6.3H_2O$. 26½ g. dissolved in 500 cc. of water.

*Potassium Hydroxide,* KOH. The "sticks" should be kept in well stoppered bottles and dissolved in water when needed.

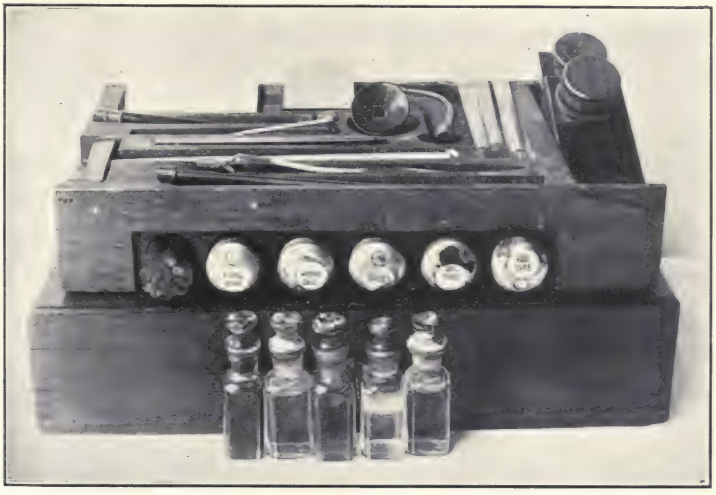


FIG. 387.— The Butler blowpipe set suitable for field use.*

*Silver Nitrate,* $AgNO_3$. 21½ g. dissolved in 500 cc. of water. The solution should be kept in amber colored bottles.

*Sodium Nitroferricyanide,* $Na_2Fe(NO)(CN)_5$. Solution should be prepared as needed.

*Stannous Chloride,* $SnCl_2.2H_2O$. Solid reagent.

*Sulphuric Acid,* $H_2SO_4$. Used at times in its concentrated form, also diluted with four parts of water. In diluting the acid should be added very slowly to the water.

*Yellow Ammonium Sulphide,* $(NH_4)_2S_x$. Add flowers of sulphur to concentrated ammonia and saturate the solution with $H_2S$. Dilute with two volumes of water. The flask should be cooled with running water while being charged with $H_2S$.

* Arranged by Professor G. M. Butler and sold by the Denver Fire Clay Company, Denver, Colorado.

On account of the ease with which blowpipe reactions may be obtained and the simplicity of the equipment necessary, various portable sets suitable for field work have been arranged. One of the best is the Butler Blowpipe set, illustrated in Fig. 387.

## STRUCTURE AND USE OF THE FLAME

**Structure of the Flame.**—The structure of the flame is essentially the same whether produced by burning a gaseous, liquid, or solid fuel. If a small luminous flame of the Bunsen burner be examined carefully, it will be noted that four more or less distinct zones are present (Fig. 388). Immediately above the burner is a dark cone, *a*, consisting primarily of unburned gases. Surrounding the dark zone and extending beneath the luminous mantle, is a small, blue, non-luminous zone, *b*. The strongly luminous region, *c*, which emits a bright yellow light, constitutes the largest portion of the luminous flame.

FIG. 388.—Structure of luminous flame.

In general, luminosity may be due to three causes operating either separately or jointly in increasing the light producing property of a flame. These causes are (1) the temperature of the flame, (2) the density of the flame gases, and (3) the presence of solid particles which are heated to incandescence. In the case of the Bunsen burner fed with ordinary coal-gas the luminosity is unquestionably due to the presence of solid particles of carbon. The illuminants, which determine the light giving property of a coal-gas flame, are the unsaturated hydrocarbons, such as ethylene $C_2H_4$, acetylene $C_2H_2$, and benzene $C_6H_6$. Due to the heat of combustion these hydrocarbons undergo dissociation. Ethylene breaks down giving acetylene and hydrogen, while the acetylene yields carbon and hydrogen, thus explaining the cause of the luminosity. The equations expressing this dissociation may be written as follows:

$$C_2H_4 \rightarrow C_2H_2 + H_2$$
$$C_2H_2 \rightarrow 2C + H_2$$

Finally surrounding the luminous mantle we have an outer, non-luminous, invisible zone, *d*, in which due to the oxygen of the air there is almost complete oxidation yielding as end products $CO_2$ and $H_2O$.

The Bunsen flame may be modified by inserting an inner tube which is flattened at one end and cut off obliquely, so that the blowpipe flame can be directed downward. The tube also acts as a support for the blowpipe.

**Oxidizing and Reducing Flames.**—The oxidizing blowpipe flame is produced by inserting the tip of the blowpipe into the luminous flame, which should be about 4 cm. in height, and blowing a gentle but

steady current of air. The flame is directed slightly downward and immediately becomes non-luminous, with the possible exception of a very small luminous region above the blow pipe tip Two well-defined non-luminous zones are radily produced, *a* and *b*, Fig. 389. The non-luminosity of this flame may be explained by the dilution and cooling effect of the air introduced into the flame gases, thus preventing the dissociation of the hydrocarbons which is so essential for the production of luminosity. Not only does the flame become non-luminous but it is also reduced in size. Since the same amount of gas is consumed and the ultimate end products are the same in both cases, the heat liberated would likewise be the same in both instances. As the non-luminous flame is smaller it follows that the average temperature of this flame must necessarily be higher than that of the luminous flame. The zone *a* is slightly reducing in character due to the presence of CO in this region. For oxidation purposes the substance to be tested should be placed as indicated by the position of the loop (Fig. 389). When placed in this position the highly heated substance readily unites with the oxygen of the atmosphere.

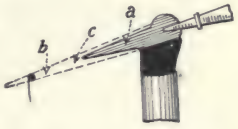


FIG. 389.—Oxidizing flame.

The oxidizing blowpipe flame is also frequently employed in testing the fusibility of minerals. The hottest portion of this flame is to be found at *c*. In testing for fusibility the fragment, which should extend beyond the tip of the forceps, should be small, possess sharp edges, and be held in the hottest portion of the flame. If the sharp outlines are rounded the mineral is said to be fusible. The degree of fusibility may be roughly determined by comparison with the fusibility of minerals comprising a standard scale. It is quite important that fragments should be chosen of approximately the same size. The generally accepted *Scale of Fusibility* is composed of the following six minerals beginning with the most fusible.

*Stibnite*, fuses readily in a candle flame, also in a closed tube.

*Chalcopyrite*, fuses in the luminous gas flame, but with difficulty in a closed tube.

*Almandite* (Garnet), fuses readily in the blowpipe flame, infusible in the luminous gas flame.

*Actinolite*, edges are readily rounded in the blowpipe flame.

*Orthoclase*, edges are fused with difficulty in the blowpipe flame.

*Bronzite*, only the sharpest splinters are rounded by fusion.

The reducing blowpipe flame is produced by placing the blowpipe tip just outside of the flame while blowing a gentle current of air (Fig. 390). The flame is tilted sideways but retains its luminosity. A fragment held in the luminous portion of this flame will suffer reduction by virtue of the hot carbon particles of the flame. Thus by

simply shifting the position of the blowpipe and regulating the strength of the blast, entirely opposite chemical effects may be produced. The purity of the oxidizing and reducing flames may be readily tested by dissolving a few small particles of $MnO_2$ in a borax bead on a platinum wire. In the oxidizing flame the color of the bead should be reddish violet, while under the influence of the reducing flame the color should entirely disappear.

FIG. 390.—Reducing flame.

**Scope of the Chemical Reactions.**—The reactions to be described will be presented in the following order:

1. Reactions on plaster tablet.
   (*a*) Assay heated *per se.*
   (*b*) Assay heated with reagents.
2. Reactions on charcoal support.
   (*a*) Assay heated *per se.*
   (*b*) Assay heated with reagents.
3. Flame colorations.
4. Bead tests.
5. Heating in open tube.
6. Heating in closed tube.
7. Special tests.
8. Summary of chemical and blowpipe tests for the more important elements.

## 1. REACTIONS ON PLASTER TABLET

On account of their smooth white surface, infusibility, conductivity, and porosity, plaster tablets have become one of the most important supports for blowpipe work. They can be employed with both solid and liquid reagents. The tablets are cheaply and easily made and their cleanliness in handling has added to their popularity.

**Per Se Reactions.**—A small depression to hold the assay is made in the lower portion of the tablet and the support held in an inclined position. Unless otherwise stated the oxidizing blowpipe flame is then directed upon the assay. The volatile constituent, either the metal itself or an oxide of the metal, is driven off by the heat and deposited upon the cooler portions of the support. The more important *per se* tests are given on page 153.

While some characteristic coatings are thus obtained by merely heating the substance *per se*, the use of reagents greatly increases the number of elements which can be easily differentiated. The reagents usually employed on the plaster support are bismuth flux, yellow ammonium sulphide, hydrobromic acid, and cobalt nitrate.

| Indication | Color of coating | Remarks |
|---|---|---|
| Cadmium | Near assay, reddish brown to greenish yellow, at times somewhat iridescent. At a distance brownish black. | Film is due to an oxide, is permanent, and is best obtained from metallic cadmium. |
| Carbon | Brownish black, non-volatile coating. | Obtained from carbonaceous material, such as asphalt. |
| Molybdenum | In oxidizing flame, near assay, yellowish white, crystalline coating of $MoO_3$. | When touched with reducing flame, white coating is immediately changed to deep blue. Example, ammonium molybdate. |
| Arsenic (metal) | White over brownish black, very volatile coating. | Garlic odor is also noted, due probably to small amount of arsine. |
| Arsenic (sulphide) | Yellowish to reddish brown coating. | When heated too rapidly, coating becomes brownish black. |
| Mercury | Drab gray, extremely volatile sublimate. | Example, HgS or HgO. |
| Selenium | Cherry red to crimson in thin layers. Black near assay where coating is very thick. | Sublimate is due to metal, is volatile, and yields reddish fumes with odor of rotten horse-radish. Example, metallic selenium. |
| Tellurium | Volatile brown to black coating, at times with narrow fringe of blue near assay. | A drop of conc. $H_2SO_4$ added to brown coating and gently heated yields effervescent pink of tellurium sulphate. Example, metallic tellurium. |
| Silver | Yellowish coating near assay. When touched with reducing flame, becomes brownish and mottled. | Coating is permanent and requires high heat. Reducedmetal may also be noted. Example, $AgNO_3$. |
| Gold | Slightly purple to rose colored coating near assay. | Requires very intense heat and is best seen when tablet is cold. |

**Reactions with Bismuth Flux and Yellow Ammonium Sulphide.** One part of the powdered mineral is intimately mixed with three parts of bismuth flux (consisting of two parts S, one part Kl, and one part $KHSO_4$) and heated on a plaster support. In nearly every instance highly colored, volatile iodide coatings are obtained which condense

on the cooler parts of the tablet. Similarly colored sublimates can be easily differentiated by the use of yellow ammonium sulphide, which transforms the iodide films to sulphides. The accompanying table summarizes the most satisfactory iodide reactions.

| Indication | Color of coating | Remarks |
|---|---|---|
| Arsenic | Lemon to orange yellow coating. Coating disappears when subjected to ammonia fumes. | A drop of $(NH_4)_2S_x$ on coating yields yellow ring. Single drop of $NH_4OH$ dissolves ring completely. |
| Antimony | Orange to peach red sublimate. Disappears when subjected to ammonia fumes. | A drop of $(NH_4)_2S_x$ on coating produces orange red ring, which is not dissolved by single drop of $NH_4OH$. |
| Lead | Chrome yellow coating. | $(NH_4)_2S_x$ applied to film yields black spot, often surrounded by reddish cloud. |
| Thallium | Orange yellow film near assay, with purplish-black band at distance. Entire coating ultimately changes to yellow. | $(NH_4)_2S_x$ applied to yellow coating gives chocolate brown spot. |
| Bismuth | Chocolate brown with underlying crimson. Yellowish on outer margins. | When subjected to ammonia fumes brown coating changes to orange yellow and then to cherry red. |
| Mercury | Combination of scarlet, yellow, and greenish-black. | If strongly heated predominating color is yellowish-green. |
| Silver | Slight yellowish coating near assay. | Requires intense heat. When touched with reducing flame becomes pinkish brown and somewhat mottled. |
| Selenium | Reddish brown to scarlet. | Reddish fumes given off. Flame is colored indigo blue. |
| Tellurium | Purplish brown to black coating. | A drop of conc. $H_2SO_4$ added to coating and gently heated yields an effervescent pink. |

**Combination of Elements.**—On account of the difference in degree of volatility of the iodides, it is not difficult at times to determine more than one element, capable of giving iodide coatings, at a single operation.

Thus, in the case of jamesonite, $Pb_2Sb_2S_5$, when the powder is heated with bismuth flux, the peach red antimony iodide coating is the first to appear at a distance from the assay. As the temperature is increased the less volatile chrome yellow coating of lead iodide forms near the assay. The use of yellow ammonium sulphide can also be used to advantage to detect such a combination. Near the assay a black spot with a reddish cloud indicates the presence of lead, while at a distance a well defined red antimony ring is obtained. Iodides of the same or nearly the same degree of volatility are deposited together producing a compound coating with a resultant color which may serve to indicate the individual components.

**Reactions with Hydrobromic Acid.**—The porosity of the plaster tablet lends itself readily to the application of the liquid reagent hydrobromic acid. To the assay, placed in a slight depression as heretofore, is slowly added 6 to 8 drops of the acid. The liquid is quickly absorbed by the support and returned as needed to the assay when the latter is heated with the blowpipe flame. Hydrobromic acid can be prepared by passing $H_2S$ through a mixture of bromine in water until the red color of the liquid bromine disappears. The elements not previously recorded, which yield bromide reactions, are copper and iron.

| Indication | Color of coating | Remarks |
|---|---|---|
| Copper | Volatile, purplish coating, mottled with black. | On standing frequently changes to yellow. Flame is colored green. |
| Iron | Rust colored spots. | Non-volatile and deposited near assay. |

As the copper bromide is more volatile than that of the iron it is possible to detect both in a single operation. By applying the blowpipe flame to the space immediately surrounding the assay, the copper coating can easily be driven to the upper portions of the tablet thus revealing the rust colored spots of iron near the assay. In addition to the copper and iron reactions, molybdenum, bismuth, lead, and mercury may also produce the following colored films with HBr.

*Molybdenum*—volatile, blue to bluish green coating.

*Bismuth*—volatile, yellow or crimson sublimate.

*Lead*—canary yellow film.

*Mercury*—volatile yellow coating.

**Cobalt Nitrate Reactions.**—Crystallized cobalt nitrate is dissolved in 10 parts of water and kept in convenient dropping bottles. The application of this reagent is restricted to white or light colored, infusible minerals. Fusible compounds would invariably yield blue cobalt glasses.

The pulverized mineral is placed on a plaster tablet and strongly ignited with the oxidizing flame, a drop or two of cobalt nitrate is then added and the assay intensely heated a second time. Upon cooling the assay may be seen to have assumed a definite color due to combination with the cobalt oxide. If the mineral is sufficiently porous to absorb the cobalt nitrate, the liquid can be applied directly to the fragment without previous pulverization. The cobalt nitrate reactions are especially serviceable in the detection of magnesium, aluminium, zinc, and tin.

| Indication | Color | Remarks |
|---|---|---|
| MgO and minerals containing it. | Pink or pale flesh red. | Best seen when cold. Example, brucite. |
| $Al_2O_3$ and compounds containing it. Zinc silicates. | Blue. | Examples, kaolinite, hemimorphite. |
| ZnO and minerals containing it. | Bright green. | Can be applied to fragment or to white coating on charcoal Example, smithsonite. |
| $SnO_2$ | Bluish green. | Should be applied to white coating on charcoal. |

### 2. REACTIONS ON CHARCOAL SUPPORT

When plaster tablets are not available or when it is desirable to verify the presence of an element, recourse may be had to the charcoal support, for the reactions obtained on plaster and charcoal supplement each other. Plaster is the better conductor and the sublimates formed are found nearer the assay. Charcoal, on the other hand, aids the reducing flame whenever reduction is desired. Care must be exercised not to mistake the ash of the charcoal for a sublimate. The ash will form near the assay where the heat has been intense and will not obscure the grain of the charcoal, sublimates on the other hand have a tendency to conceal the grain.

**Per Se Reactions.**—A small depression is made near the edge of the charcoal and the assay is heated slowly with the oxidizing flame, while the support is held in an inclined position to catch the sublimate formed. If the assay decrepitates (snaps) when heated it should be finely pulverized and moistened with a drop of water. The films produced when heat is applied slowly are mainly oxides as is shown by the accompanying table.

| Indication | Color and character of sublimate | Remarks |
|---|---|---|
| Arsenic | White ($As_2O_3$), very volatile coating. | Deposits at distance from assay. Garlic odor often noted. |
| Antimony | Near assay, dense white coating ($Sb_2O_3$, $Sb_2O_4$). At distance, bluish. | Less volatile than arsenic coating. |
| Cadmium | Near assay—black to reddish brown (CdO). At distance, yellowish-green. | Very thin deposits show iridescent tarnish. |
| Molybdenum | Pale yellow ($MoO_3$), hot; white, cold; crystalline. | When touched with reducing flame becomes dark blue. Copper red ($MoO_2$) coating surrounding assay. |
| Lead | Dark yellow (PbO) hot; pale yellow, cold. | At times mixed with white sulphite and sulphate of lead. |
| Bismuth | Orange yellow ($Bi_2O_3$), hot; lemon yellow, cold. | Distinguished from lead by bismuth flux test. |
| Zinc | Canary yellow (ZnO), hot; white, cold. | When moistened with $Co(NO_3)_2$ and heated, becomes grass green. |
| Tin | Faint yellow ($SnO_2$), hot; white, cold. | When moistened with $Co(NO_3)_2$ and heated, becomes bluish green. |
| Selenium | Near assay, steel gray with metallic luster. At distance, white $(SeO)_2$ tinged with red (Se). | Coating colors the flame blue. Characteristic odor. |
| Tellurium | Near assay, white ($TeO_2$). At distance, gray (Te) or brownish. | Imparts pale green color to flame. |
| Thallium | White ($Tl_2O$), very volatile. | Coating colors flame bright green. |

In addition to the above, white sublimates may result from the volatilization of the chlorides of copper, lead, mercury, ammonium, and the alkalies.

While the charcoal support does not lend itself readily to the use of liquids, solid reagents such as bismuth flux and sodium carbonate are frequently employed.

**Reactions with Bismuth Flux.**—The reactions of the elements with bismuth flux on charcoal are, on the whole, rather unsatisfactory with the following two exceptions:

*Lead*—greenish yellow film.

*Bismuth*—yellowish white sublimate with crimson border.

**Reactions with Sodium Carbonate.**—The effect of heating the assay with $Na_2CO_3$ on charcoal is to augment the reducing action of the hot charcoal. This is due to the formation of reducing gases, such as CO, and possibly gaseous sodium. Under this treatment a number of substances are reduced to the metallic condition. The assay is mixed with three parts of anhydrous $Na_2CO_3$ together with some powdered charcoal obtained from the pit made to support the assay. After heating with the reducing flame for several minutes the fusion is ground with water in an agate mortar and the color, malleability, or magnetism of the reduced particles noted. In addition to reduced metal, some substances yield a sublimate, while still others are volatilized so quickly that no reduced metal is formed.

**Summary of $Na_2CO_3$ Reactions.**—The reactions of the common elements fall under three divisions.

1. *Reduced metal without sublimate.*

(*a*) Malleable buttons—Cu, Ag, Au.

Copper—confirm by dissolving in $HNO_3$ acid and note blue color when solution is made alkaline with $NH_4OH$.

Silver—dissolve in $HNO_3$ acid and note white precipitate when a drop of HCl acid is added. The precipitate is soluble in $NH_4OH$.

Gold—confirm by dissolving in aqua regia, evaporate almost to dryness, and dissolve, the residue in a little water. Add a few drops of freshly prepared $SnCl_2$. Finely divided precipitate is formed which renders the solution purple by transmitted light and brownish by reflected light.

(*b*) Magnetic particles—$Fe_3O_4$, Co, Ni.

Iron—dissolve in $HNO_3$ acid, add a few drops of potassium ferrocyanide. Dark blue precipitate will be formed.

Cobalt—dissolve in borax bead on end of platinum wire. Note blue color.

Nickel—dissolve in $HNO_3$ acid, make alkaline with $NH_4OH$. Add several cc. of alcoholic solution of dimethylglyoxime. Bright red precipitate is produced.

2. *Reduced Metal with Sublimate.*

Antimony—dense white coating near assay. Gray brittle button.

Lead—sulphur yellow coating. Gray malleable button.

Bismuth—lemon yellow sublimate. Reddish white, brittle button.

Tin—white coating near assay, yellow while hot. White malleable button.

3. *Sublimate without Metal.*

Arsenic—white volatile film. Garlic odor.

Zinc—white film, yellow while hot.

Cadmium—reddish brown to orange colored sublimate with tarnish colors.

Selenium—steel gray coating and brown fumes with characteristic odor.

Tellurium—white coating with reddish or dark yellow border.

Molybdenum—white coating, changed to dark blue when exposed to the reducing flame.

Sodium carbonate can also be profitably employed in the detection of sulphur, manganese, chromium, and phosphorus.

**Test for Sulphur.**—The powdered sulphide, mixed with 3 to 4 parts of anhydrous $Na_2CO_3$, is thoroughly fused on a charcoal support. In case of sulphates some powdered charcoal should be added to the $Na_2CO_3$. After fusion the mass ($Na_2S$) is removed from the support and crushed. One-half of the powder is then placed upon a clean silver coin and several drops of water are added. A dark brown or black stain ($Ag_2S$) indicates sulphur, provided selenium and tellurium are absent. To check this sulphur test the remaining powder is placed on a watch glass. Several drops of water are then added, followed by a drop or two of freshly prepared sodium nitroferricyanide, $Na_2Fe(NO)(CN)_5$. An intense red purple coloration is indicative of sulphur. It is preferable to use an alcohol flame for the fusion, as the gas flame may contain sulphur compounds. Also there is a tendency for the fusion to sink into the charcoal and for this reason the same pit should be used but once.

**Tests for Manganese and Chromium.**—Powdered manganese compounds should be mixed with a small amount of $KNO_3$ and placed in a shallow depression made in a charcoal support. Sodium carbonate is then spread over this mixture. The blowpipe flame is directed for a brief period on a given spot until incipient fusion takes place. Upon cooling this fused area assumes a bluish-green color due to the formation of sodium manganate, $Na_2MnO_4$. Long fusion is to be avoided as the manganate loses its color, due to reduction brought about by the charcoal. (Copper compounds also yield bluish green fusions.)

Chromium compounds when fused with $Na_2CO_3$ and $KNO_3$ in a manner similar to that indicated for manganese, yield yellow colored fusions ($Na_2CrO_4$). This test for chromium is, however, unsatisfactory in the presence of lead or vanadium as these elements also yield yellow masses. Instead of performing the fusion on charcoal, manganese or chromium compounds may be dissolved in a $Na_2CO_3$ bead held in a loop of platinum wire. Under the influence of the oxidizing flame of the blowpipe the bead will assume the color indicated above. If the platinum wire test is used, it is not necessary to add $KNO_3$ to the $Na_2CO_3$.

**Test for Phosphorus.**—Phosphates of aluminium and the heavy metals should be fused with two parts of $Na_2CO_3$ on charcoal, and the powdered fusion then ignited in a test tube with magnesium ribbon. The phosphorus is thereby converted into a phosphide ($Mg_3P_2$), which upon the addition of a few drops of water liberates the unpleasant,

garlic-like odor of phosphine, $PH_3$, which produces a black coloration when brought in contact with filter paper moistened with $AgNO_3$. Phosphates of the alkalies and alkaline earths may be ignited with magnesium ribbon directly without previous fusion. This test for phosphorus cannot be relied upon in the presence of arsenic or antimony.

A more reliable test for phosphorus is the following: the phosphate is dissolved in $HNO_3$ acid (if insoluble, fusion with $Na_2CO_3$ should precede solution in acid) and a portion of the filtrate added to an excess of ammonium molybdate solution. Upon standing or upon slightly warming, a yellow precipitate of ammonium phosphomolybdate will be formed.

### 3. FLAME COLORATIONS

A number of compounds and especially those of the alkalies and alkaline earths, impart to the non-luminous flame of the Bunsen burner or to the oxidizing flame of the blowpipe, characteristic colors which may be used for their identification. As the intensity of the flame coloration depends upon the volatility of the salt used, and inasmuch as chlorides are generally more volatile than other compounds, the best results are ordinarily obtained by moistening the powder with HCl. In a few instances moistening with $H_2SO_4$ is preferable. The powder is introduced into the Bunsen flame by means of a clean platinum wire, or a very thin splintery fragment of the mineral, moistened with acid, may be held by the forceps in the non-luminous portion of the oxidizing blowpipe flame. Fusible metals and arsenic should not, however, be heated in contact with platinum tipped forceps. To detect alkalies in silicates, decomposition may be brought about by mixing the assay with an equal volume of powdered gypsum before introducing into the hottest portion of the Bunsen flame. It is even possible at times to detect the individual components when several flame coloring elements occur together. This may be accomplished by making use of either (1) spectroscope, or (2) the difference in degree of volatility of the constituents present, or (3) colored screens.

**Spectroscope.**—For blowpipe work the direct vision pocket spectroscope is very useful. The best instruments are provided with a scale and a comparison prism by means of which the spectrum of an unknown substance can be directly compared with that of a known substance. When a colored flame is observed through a spectroscope, light colored lines are perceived upon a dark back ground. The color, position, and grouping of the lines are used as the basis for the recognition of the elements.

**Difference in Volatility.**—In a mixture the flame coloring constituents can often be detected readily without the use of the spectroscope, by noting the *difference in the degree of volatility of the components.* In general the alkalies (Na, K, Li) are more volatile than the alkaline

earths (Ca, Ba, Sr), and by holding the platinum wire about 1 mm. from the outer non-luminous Bunsen flame sufficient heat is encountered to volatilize the alkalies, while insertion in the hotter portion of the flame is necessary to detect the alkaline earths.

**Colored Screens.**—These are also extensively employed in analyzing flame mixtures. Screens composed of colored glass or celluloid transmit certain rays while others are entirely absorbed. Thus, blue glass absorbs certain red and green rays together with those of yellow. One of the most effective screens on the market at present is the *Merwin Flame Color Screen*. This celluloid screen is composed of three colored strips, one blue, one violet, and one blue over violet. The strips are stained so as to absorb the orange and yellow portions of the spectrum. Observations should be made through all three divisions of the screen. In the accompanying table flame colorations will be recorded as seen with and without the Merwin color screen.

| Indication | Flame color | Through Merwin screen | Remarks |
|---|---|---|---|
| Calcium | Yellowish-red | 1. Flash of greenish-yellow[1]<br>2. Invisible<br>3. Flash of crimson | Color flashes out at the moment salt becomes incandescent. Calcium minerals becomes alkaline upon ignition. |
| Strontium | Crimson | 1. Invisible<br>2. Invisible<br>3. Crimson | Strontium minerals become alkaline upon ignition. If to solution of Sr salt few drops of $BaCl_2$ are added, red color (Sr) will appear *after* green of Ba. Sr solutions yield white ppt. when few drops of $H_2SO_4$ are added. (Difference from Li.) |
| Lithium | Carmine | 1. Invisible<br>2. Invisible<br>3. Crimson | Lithium minerals do not become alkaline upon ignition. If to solution of Li salt few drops of $BaCl_2$ are added, red color (Li) will appear *before* green of Ba. |
| Potassium | Pale violet | 1. Blue violet<br>2. Deep red violet<br>3. Red violet | Purplish red through blue glass. Spectroscope is necessary to distinguish between potassium, rubidium, and caesium. |
| Sodium | Intense yellow | 1. Invisible<br>2. Invisible<br>3. Invisible | Flame color should be intense and persistent to indicate sodium mineral. Invisible through blue glass. |

[1] Numerals refer to the divisions of the screen.

| Indication | Flame color | Through Merwin screen | Remarks |
|---|---|---|---|
| Copper oxide<br>Copper iodide | Emerald green | | Tinged with azure blue when moistened with HCl. |
| Thallium | Grass green | | |
| Tellurium<br>Antimony | Pale green | | |
| Phosphorous | Pale bluish green | 1. Green<br>2. Invisible<br>3. Red violet | Should be moistened with con. $H_2SO_4$. Color not very distinct. |
| Boron | Yellowish green | 1. Bright green<br>2. Faint green<br>3. Faint green | For borates decomposed by $H_2SO_4$: To mineral placed in porcelain dish, add alcohol and concentrated $H_2SO_4$, apply match. Note yellowish green color of flame. For borates not decomposed by $H_2SO_4$: Mix powder with 3 parts of boracic acid flux (3 parts $KHSO_4$, 1 part $CaF_2$), introduce into flame by means of hot Pt. wire. Flash of green will be seen due to $BF_3$. |
| Barium | Yellowish green | 1. Bright green<br>2. Faint green<br>3. Faint green | Barium minerals become alkaline upon ignition. |
| Molybdenum | Faint yellowish green | | If in form of oxide or sulphide. |
| Zinc | Bluish green | | Appears as bright streaks in flame. |
| Copper chloride | Azure blue | 1. Bright green<br>2. Bluish green<br>3. Bluish green | Flame is tinged with emerald green. |
| Selenium | Indigo blue | | Accompanied by characteristic odor. |
| Arsenic | Livid blue | | |
| Lead | Pale azure blue | | Tinged with green in outer parts. |
| Indium | Corn flower blue | | |

### 4. BEAD TESTS

The oxides of many of the metals form complex compounds of characteristic colors when dissolved at a high temperature in borax, $Na_2B_4O_7.10H_2O$, or microcosmic salt (salt of phosphorus) $HNaNH_4PO_4.4H_2O$. The support usually employed for this work is a No. 28 B. & S. gauge platinum wire about 10 cm. long which has been fused into the end of a piece of glass tubing. Unoxidized metals as well as compounds sulphur, arsenic, and antimony should be roasted until the volatile constituents have been removed and the residue converted into an oxide.

| Oxide of | Borax bead | | Microscopic salt bead | |
|---|---|---|---|---|
| | Oxidizing flame | Reducing flame | Oxidizing flame | Reducing flame |
| Mn | reddish violet | colorless | violet | colorless |
| Co | blue | blue | blue | blue |
| Cu | blue | opaque red | blue | opaque red |
| Ni | reddish brown | opaque gray | straw to reddish yellow | yellow to reddish yellow |
| Fe | yellow | pale green | colorless to yellowish brown | colorless to pale violet |
| U | yellow | pale green to colorless | yellowish green | bright green |
| Cr | grass green | emerald green | emerald green | emerald green |
| V | yellowish green | emerald green | light yellow | emerald green |
| Ti | colorless | brownish violet | colorless | violet |
| Mo | colorless | brown | colorless | pure green |
| W | colorless | yellow to yellowish brown | colorless | fine blue |
| Si | | | insoluble skeleton | insoluble skeleton |

A small circular loop made at the end of the platinum wire is heated and then touched to the borax or microcosmic salt. Sufficient material will adhere to form, when heated before the blowpipe flame, a clear colorless glass. In the case of the microcosmic salt bead the heat should be applied slowly as the material has a tendency to drop from the wire due to the escape of water and ammonia. By touching the hot bead to a

few particles of the finely crushed oxide, and again heating in the oxidizing flame of the blowpipe, solution and coloration of the fusion will frequently result. The color of the bead should be noted after it has been subjected to the oxidizing flame and again after the reducing flame has been applied. The action of the reducing flame may be greatly accelerated by dissolving a small fragment of SnO or $SnCl_2$ in the bead. The colors observed with the microcosmic salt are not in every instance identical with those of the borax. In general the tests obtained with the borax flux are more delicate, while the microcosmic salt fusions yield a greater variety of colors. The removal of the bead from the support for preservation may be accomplished by simply straightening the wire. In the table on page 163, the colors listed are those of the cold beads obtained from the unmixed oxides.

Of the beads enumerated, the first eight are extremely serviceable. In order to detect Ni in the presence of Co or any other oxide which ordinarily would obscure the nickel test, the procedure should be as follows: dissolve several beads in $HNO_3$ acid and add $NH_4OH$ until the solution becomes alkaline. To the filtrate add several cc. of an alcoholic solution of dimethylglyoxime. A scarlet precipitate indicates Ni. This is an extremely delicate and characteristic test.

$$Ni(NO_3)_2 + 2NH_4OH + 2C_4H_8N_2O_2 = (C_8H_{14}N_4O_4)\,Ni + 2NH_4NO_3 + 2H_2O.$$

### 5. OPEN TUBE REACTIONS

Hard glass tubing, 15 to 20 cm. long and about 5 mm. in diameter, is employed in blowpipe work to note the effects of a current of air when permitted to pass over a highly heated substance. These open tubes should be bent slightly near one end in order to hold the material more conveniently which should be in a powdered condition to expose the maximum amount of surface. The tube is held in an inclined position in the flame, apply heat first above the assay to insure a good current of air through the tube, and then directly under the mineral (Fig. 391). In most instances oxidation results and the volatile material either escapes in the form of a gas with a characteristic odor, or a sublimate is formed which deposits upon the cooler portions of the tube. The temperature should be increased gradually so as not to volatilize the substance in an unoxidized condition. The results of open tube tests may be summarized as follows:

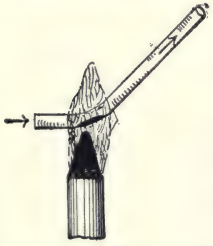


FIG. 391.—Heating in open tube.

#### *A.* Gases with Characteristic Odors

1. Odor of burning sulphur with bleaching properties. The gas liberated is $SO_2$. The test is very delicate and is extremely useful in

testing for sulphur or sulphides. If oxidation is not complete, due to too rapid heating or an insufficient air supply, free sulphur may also deposit on the sides of the tube.

2. Garlic odor. Produced when arsenic compounds are rapidly heated and not completely oxidized.

3. Odor of rotten horseradish. Obtained from selenium compounds when volatilized.

*B.* **Sublimates**

| Indication | Character of the coating | Remarks |
|---|---|---|
| Arsenic<br>Arsenides<br>Sulphides of arsenic | White, crystalline, and volatile sublimate ($As_2O_3$). Crystals are minute octahedrons. | Metallic mirror or yellow coating of arsenic sulphide indicates too rapid heating. |
| Antimony<br>Sulphides of antimony | Dense white fumes which partly escape and partly condense as white powder. Both $Sb_2O_3$ and $Sb_2O_4$ are formed. | $Sb_2O_3$ is white, slowly volatile, and crystalline. $Sb_2O_4$ is non-volatile and amorphous. |
| Bismuth sulphide | White, non-volatile powder ($BiSO_4$). | Fusible to yellow drop. |
| Bismuth (free from sulphur) | Brown while hot; yellow when cold ($Bi_2O_3$). | Sublimate is fusible. |
| Tellurium<br>Tellurides | Snow white, non-volatile sublimate ($TeO_2$). | Upon heating fuses to colorless drops. |
| Lead chloride | White, partially volatile sublimate (PbOCl). | Fusible to yellow drops. |
| Lead sulphide | Non-volatile, white powder formed near assay ($PbSO_4$). | Fusible to yellow drops, white when cold. |
| Selenium<br>Selenides | Near assay, steel gray, volatile coating consisting of radiating needles ($SeO_2$). | At distance reddish due to finely divided Se. |
| Molybdenum oxide or sulphide | Yellow when hot, white when cold ($MoO_3$). | Collects near assay as mass of delicate crystals. |
| Mercury<br>Amalgams | Minute, gray, metallic globules. Volatile (Hg). | Globules unite by rubbing with strip of paper. |

## 6. CLOSED TUBE REACTIONS

Closed tube reactions are carried out in hard glass tubes about four inches long and 6 mm. in diameter, which are closed at one end. The

assay is introduced in the form of small fragments and heat applied gradually. The object of this treatment is to note the effect of heat without oxidation as the air is practically entirely excluded (Fig. 392). These are known as the *per se* tests. Closed tubes may also be profitably employed in heating the assay with $KHSO_4$.

### *A.* Per Se Tests

The applicaton of heat alone may produce such phenomena as:

(*a*) *Change in appearance or character of assay.*

1. *Change in Color.*—The more important minerals thus affected are:

Copper minerals—blue or green, become black when hot; black, cold.

Zinc minerals—white or colorless, become pale yellow when hot; white, cold.

Manganese and cobalt minerals—pink, become black when hot; black, cold.

FIG. 392.—Heating in closed tube.

Lead and bismuth minerals—white or colorless, become dark yellow to brown when hot; pale yellow to white, cold.

Iron minerals—green or brown, become black when hot; black, cold.

Hematite—dark red, becomes black when hot; dark red, cold.

2. *Fusion.*—Only minerals with a fusibility below one and one-half in the scale of fusibility melt when heated in a closed tube *per se.*

3. *Carbonization.*—Indicating organic substances.

4. *Phosphorescence.*—Some minerals when heated to a temperature below redness and viewed in a dark room will be seen to emit colored light. Many varieties of fluorite when heated to 150° C. emit a purple or green light.

5. *Decrepitation.*—Alkaline chlorides, galena, and many minerals snap and break down to a fine powder when heated. This behavior is usually the result of unequal expansion or due to the presence of water held mechanically.

6. *Magnetization.*—Iron minerals frequently become magnetic upon the application of heat.

(*b*) *Formation of Gases in the Tube.*

1. *Carbon Dioxide.*—Colorless and odorless gas. A drop of lime water held in a loop of platinum wire becomes turbid. Indicates carbonates.

2. *Oxygen.*—A glowing splinter takes fire when held in the tube. Indicates peroxides, nitrates, chlorates, bromates, or iodates.

3. *Ammonia.*—Characteristic odor and alkaline reaction. More pronounced when heated with $Na_2CO_3$. Indicates ammonium salts or

organic compounds containing nitrogen. If the latter, the mass usually chars.

(*c*) *Formation of Sublimates.*

1. *Colorless or White Sublimates*

| Indication | Character of sublimate | Remarks |
|---|---|---|
| Water | Colorless, volatile liquid which forms on the cooler part of the tube. | Indicates water of crystallization or hydroxyl. Neutral if pure, may show acid or alkaline reaction. |
| Ammonium salts | White, very volatile. | |
| Lead chloride | White, fusing to yellow drops. | |
| Mercurous chloride | White, yellow when hot. | Sublimate is infusible. |
| Mercuric chloride | White, yellow when hot. | Sublimate is fusible. |
| Antimony oxide | White, fusible. | Sublimate consists of needle like crystals. |
| Arsenic oxide | White, volatile. | Sublimate consists of octahedral crystals. |
| Tellurium oxide | Pale yellow, hot; colorless to white globules, cold. | Obtained from tellurium and a few of its compounds. |

2. *Colored Sublimates*

| Indication | Character of sublimate | Remarks |
|---|---|---|
| Sulphur<br>Some sulphides | Brownish red liquid, hot; pale yellow crystalline solid, cold. | Due to the formation of free sulphur. |
| Sulphides of arsenic | Dark red liquid, hot; reddish yellow solid, cold. | From realgar, orpiment and sulpharsenites. |
| Sulphides of antimony | Black when hot; reddish brown when cold. $Sb_2OS_2$ is formed. | From sulphides and sulphantimonites. |
| Sulphide of mercury | Brilliant black solid. | Yields a red powder when rubbed. |
| Selenium<br>Selenides | Black fusible globules. Red when rubbed. | Sublimate forms only at high temperature. |
| Arsenic<br>Arsenides | Brilliant black sublimate. Gray and crystalline near heated end. | Garlic odor noted when tube is broken below mirror and gently heated. |
| Mercury<br>Amalgam | Minute, gray metallic globules. | Globules unite when rubbed. |
| Tellurium<br>Tellurides | Black fusible globules. | Sublimate forms at high temperature. |

### *B.* Reactions in Closed Tube with $KHSO_4$

The detection of volatile acids may be accomplished by gently heating the assay with an equal volume of $KHSO_4$.

1. *Colored Gas Evolved*

| Indication | Character of gas | Remarks |
|---|---|---|
| Nitrates<br>Nitrites | Reddish brown with pungent odor. | Gas liberated is $NO_2$. |
| Chlorates | Yellowish green fumes with odor of chlorine. | Gas liberated is $ClO_2$. |
| Iodides | Violet vapors accompanied by a black metallic sublimate. | Iodine is set free. |
| Bromides<br>Bromates | Heavy brownish red vapor with pungent odor. | Bromine is liberated. Best seen when tube is held against a white back ground. |

2. *Colorless, Odorous Gas Evolved*

| Indication | Character of sublimate | Remarks |
|---|---|---|
| Sulphates<br>Sulphites | Suffocating odor with bleaching properties. | Gas is $SO_2$. |
| Chlorides | Colorless gas which fumes strongly when in contact with $NH_4OH$. | Gas is HCl. |
| Fluorides | Gas which etches the tube above the assay. | Gas is HF. |
| Sulphides | Gas with odor of decayed eggs. Blackens lead acetate paper. | Gas is $H_2S$. |
| Acetates | Gas with odor of vinegar. | Gas is $C_2H_4O_2$. |

3. *Colorless, Odorless Gas Evolved*

| Indication | Character of sublimate | Remarks |
|---|---|---|
| Carbonates | A drop of lime water held in a loop of platinum wire becomes turbid. | Gas is $CO_2$. |
| Oxalates | A gas which burns with a blue flame. | Gas is CO. |

## 7. SPECIAL TESTS

In this section reactions will be listed which do not conveniently fall under any of the previous divisions. They are nevertheless extremely useful in mineralogical determinations. The reactions given below are to be considered as individual tests and not in any way related to one another.

**1. Tests for Calcite and Aragonite.**—Powdered calcite when boiled for a few minutes in a dilute solution of cobalt nitrate remains white or in the presence of organic matter becomes yellowish, while aragonite turns lilac red due to the formation of a basic cobalt carbonate. This is commonly known as *Meigen's test.* The change in color is more readily detected by washing the powder by decantation after boiling. Inasmuch as barium or strontium carbonate and precipitated basic magnesium carbonate give the same reactions as aragonite, and dolomite the same as calcite, it is absolutely necessary to first establish the fact that you are dealing with one of the modifications of $CaCO_3$ before applying the cobalt nitrate test.

**2. Tests for Calcite and Dolomite.**—(*a*) Calcite dissolves in acetic acid with a brisk evolution of $CO_2$, while dolomite is not appreciably affected by the cold acid.

(*b*) J. Lemberg has noted that powdered calcite is colored violet when treated with a solution of aluminium chloride and extract of logwood, while dolomite remains unchanged. The reaction is caused by the precipitation upon the calcite of $Al(OH)_3$ which absorbs the dye and acts as a mordant. To observe the color change the powder should be washed by decantation. The Lemberg solution is prepared by boiling for twenty minutes a mixture of 4 grams of $AlCl_3$, 6 grams extract of logwood, and 60 grams of water, with constant stirring and with the addition of the amount of water lost by evaporation.

(*c*) According to F. Cornu calcite and dolomite may be distinguished by covering the powder with a small amount of water and adding a few drops of phenolphtalein solution. Upon shaking, the aqueous solution above the calcite assumes a pink to red color while the dolomite is not appreciably affected.

**3. Test for Cassiterite** ($SnO_2$).—As the usual colors of cassiterite are various shades of yellow, brown, or black a change in the appearance of the mineral can be utilized for its detection. This can readily be accomplished by placing fragments of cassiterite in contact with metallic zinc and adding dilute HCl acid. The nascent hydrogen liberated reduces the $SnO_2$ and the mineral becomes coated in a few minutes with a thin gray layer of metallic tin.

**4. Reduction Tests with Metallic Tin and HCl Acid.**—Rapid tests for the elements titanium, tungsten, niobium and, vanadium may be

carried out by dissolving the $Na_2CO_3$ fusion in HCl and adding a few fragments of metallic tin. The hydrogen evolved reduces the salts of the rarer elements producing colored solutions or precipitates which are used to detect the presence of the element involved. The following table indicates the changes referred to.

| Indication | Color of solution | Remarks |
|---|---|---|
| Titanium | Violet color. | Best seen when evolution of $H_2$ ceases. |
| Tungsten | Dark blue. | Color due to heavy precipitate which upon standing settles to bottom. |
| Niobium | Pale blue. | Color disappears upon addition of water. |
| Vanadium | Blue, green, finally blue violet. | Metallic zinc should be used instead of tin. |

Instead of using a reducing agent for the detection of titanium and vanadium, $H_2O_2$ in an acid solution can be employed. The oxidation reactions are more delicate than the corresponding reduction tests.

| | | |
|---|---|---|
| Titanium | Amber colored solution. | The fused mass should be dissolved in 1 : 1 $H_2SO_4$ solution. |
| Vanadium | Reddish brown solution. | Dissolve fusion in $HNO_3$. |

## 8. SUMMARY OF CHEMICAL AND BLOWPIPE TESTS FOR THE MORE IMPORTANT ELEMENTS

For convenience of reference the most reliable tests for the various elements are here summarized. The wet chemical tests included in this summary are often extremely useful and supplement the dry reactions.

### Aluminum (Al)

(1) *Ignition with Cobalt Nitrate.*—Infusible light colored aluminum minerals when moistened with a drop or two of cobalt nitrate and intensely ignited assume a blue color. (Zinc silicates give a similar reaction.)

(2) *Precipitation with Ammonia.*—When an acid solution containing aluminum is rendered alkaline with $NH_4OH$, a white gelatinous precipi-

tate of $Al(OH)_3$ is formed. This precipitate is readily dissolved in a warm KOH solution.

### Ammonium ($NH_4$)

(1) *Heating in Closed Tube.*—When boiled with a solution of KOH, or heated with $Na_2CO_3$ or CaO, ammonia is evolved which is recognized by its odor, alkaline reaction, and white fumes when brought in contact with HCl.

### Antimony (Sb)

(1) *Sublimate on Plaster Tablet.*—Antimony minerals mixed with bismuth flux and heated on a plaster support yield an orange to peach red sublimate. A drop of $(NH_4)_2S_x$ upon the coating produces an orange red ring.

(2) *Sublimate on Charcoal.*—When heated with the oxidizing flame on charcoal a dense white sublimate of $Sb_2O_3$ is formed near the assay. The coating is volatile and bluish in thin layers. The fumes have no distinctive odor (difference from arsenic).

(3) *Heating in Open Tube.*—Antimony minerals yield dense white fumes which partly escape and partly condense as a white powder.

(4) *Heating with Concentrated Nitric Acid.*—$HNO_3$ oxidizes antimony and its sulphides to metantimonic acid which is a white precipitate, insoluble in both water and $HNO_3$.

### Arsenic (As)

(1) *Sublimate on Plaster Tablet.*—Arsenic minerals mixed with bismuth flux and heated on a plaster support yield a lemon yellow sublimate. A drop of $(NH_4)_2S_x$ on the coating produces a yellow ring.

(2) *Sublimate on Charcoal.*—Arsenic, arsenides, and sulphides of arsenic heated with the oxidizing flame on charcoal give a very volatile white coating of $As_2O_3$ which deposits at some distance from the assay. The fumes have a characteristic garlic odor.

(3) *Heating in Open Tube.*—Arsenic, arsenides, and sulphides produce a white, volatile, and crystalline sublimate of $As_2O_3$. Too rapid heating may yield a metallic mirror instead of the oxide.

(4) *Heating in Closed Tube.*—Arsenic and arsenides give a bright metallic mirror. When the tube is broken below the mirror and heated, a garlic odor will be noted. Arsenates should be mixed with powdered charcoal to cause reduction.

(5) *Precipitation as Ammonium Magnesium Arsenate.*—With few exceptions arsenic minerals are oxidized when boiled with concentrated $HNO_3$ to arsenic acid, $H_3AsO_4$. Make the solution alkaline with $NH_4OH$ and filter. To the filtrate add a few cc. of magnesia mixture ($MgCl_2$

and $NH_4Cl$), shake and let stand. White crystalline $MgNH_4AsO_4$ will precipitate.

### Barium (Ba)

(1) *Flame Test.*—When moistened with HCl barium minerals impart a yellowish green color to the flame.

(2) *Alkaline Reaction and High Specific Gravity.*—Barium compounds are characterized by rather high specific gravities and alkaline reaction with moistened turmeric paper after strong ignition.

(3) *Precipitation as Barium Sulphate.*—A few drops of dilute $H_2SO_4$ will precipitate white $BaSO_4$, insoluble in dilute acids. This test distinguishes barium from boron and phosphorus minerals which also color the flame green.

### Beryllium (Be); Also Called Glucinum

Beryllium compounds resemble very closely aluminum in their chemical reactions. A few distinguishing tests are:

(1) *Precipitation as Basic Carbonate.*—Ammonium carbonate added to a solution of a beryllium salt produces a white precipitate of beryllium carbonate, readily soluble in an excess of the reagent (difference from Al). Upon boiling the solution beryllium is precipitated as white basic carbonate.

(2) *Solution of Hydroxide in Acid Sodium Carbonate.*—A saturated solution of $NaHCO_3$ upon the hydroxides of iron, aluminum, and beryllium, dissolves the beryllium hydroxide. If the mineral is a silicate, fusion with $Na_2CO_3$ on charcoal, and evaporation to dryness with HCl for the removal of silica must precede the foregoing tests.

### Bismuth (Bi).

(1) *Sublimate on Plaster Tablet.*—When mixed with bismuth flux and heated on a plaster support bismuth minerals yield a chocolate brown coating, which is changed to a bright red when exposed to strong ammonia fumes.

(2) *Bismuth Flux on Charcoal.*—Upon charcoal the mineral mixed with bismuth flux produces a yellowish sublimate with crimson border.

(3) *Reduction on Charcoal.*—Bismuth compounds mixed with $Na_2CO_3$ on charcoal give a lemon yellow coating with white border, and reddish white brittle buttons.

(4) *Precipitation as Bismuth Oxychloride.*—If water is added to an HCl solution, which has been evaporated almost to dryness, a white precipitate of BiOCl is formed.

## Boron (B)

(1) *Flame Test.*—Some boron minerals yield a yellowish green flame when heated alone, but the majority require the application of $H_2SO_4$ or boracic acid flux. If decomposable by $H_2SO_4$, boron compounds burn with a yellowish green flame due to the formation of basic acid methyl ester, $B(OCH_3)_3$, when placed in an evaporating dish with alcohol and concentrated $H_2SO_4$ and ignited. Borates not decomposable by $H_2SO_4$ should be mixed with three parts of boracic acid flux (three parts $KHSO_4$, one part $CaF_2$) and introduced into the flame on a clean platinum wire. A flash of green indicates the liberation of the volatile boron fluoride $BF_3$.

(2) *Turmeric Paper Test.*—If turmeric paper is moistened with a dilute HCl solution of boron and dried it assumes a reddish brown color. If it is then moistened with $NH_4OH$ a bluish black or grayish blue spot results, depending upon the amount of turmeric and boric acid present. It is advisable to run a blank test at the same time. As acid solutions of zirconic, titanic, tantalic, niobic, and molybdic acids also color turmeric paper brown, this test for boron can only be employed in their absence.

## Bromine (Br)

(1) *Heating in Closed Tube with Potassium Bisulphate.*—When a bromide is heated with $KHSO_4$, heavy brownish red vapors of bromine are liberated.

(2) *Precipitation as Silver Bromide.*—A white precipitate of AgBr (soluble in $NH_4OH$) is formed when $AgNO_3$ is added to a dilute $HNO_3$ solution of a bromide.

## Cadmium (Cd)

(1) *Heating on Plaster Tablet Per Se.*—Near the assay there is formed a reddish brown to greenish yellow coating. At a distance it is brownish black. It is best obtained from the metal.

(2) *Heating on Charcoal.*—When heated on charcoal cadmium yields a film which is reddish brown near the assay and yellowish green at a distance. Very thin deposits show an iridescent tarnish.

## Calcium (Ca)

(1) *Flame Test.*—After being pulverized and moistened with HCl many calcium minerals color the non-luminous flame yellowish red. The color should not be confused with the redder and more persistent strontium flame. When viewed through the Merwin Color Screen, calcium appears as a flash of greenish yellow through division No. 1. (Distinction from Li and Sr.)

(2) *Precipitation as Calcium Oxalate.*—Ammonium oxalate added to an ammoniacal solution of calcium produces a white precipitate of calcium oxalate, $CaC_2O_4$. This precipitate will also form in a very slightly acid solution.

(3) *Precipitation as Calcium Sulphate.*—A few drops of dilute $H_2SO_4$ added to a calcium salt dissolved in a small volume of dilute HCl precipitates $CaSO_4$. Upon the addition of water and the application of heat the precipitate dissolves. (Distinction from barium and strontium.)

### Carbon (C)

(1) *Heating in Closed Tube.*—When heated, hydrocarbons such as asphaltum, albertite, or bituminous coals yield oils and tarry compounds which condense on the sides of the tube. The residue, if any, is mainly carbon. If carbon is present as carbonates, decomposition is affected with the liberation of $CO_2$ which renders a drop of lime water on a loop of Pt wire turbid.

(2) *Effervescence with Acids.*—The solution of carbonates in dilute acids takes place with brisk evolution of $CO_2$. In some instances the acid should be heated but care must be exercised not to mistake boiling for liberation of $CO_2$.

### Cerium (Ce)

*Oxidation with Hydrogen Peroxide.*—If a cerous salt is treated with a slight excess of $NH_4OH$ and then with $H_2O_2$, the white precipitate becomes reddish orange in color, due probably to $Ce(OH)_3O_2H$. To remove interfering elements procede as follows: Fuse with $Na_2CO_3$ and evaporate the HCl solution to dryness. Take up with dilute HCl and filter. Precipitate the cerous oxalate from the dilute acid solution by means of ammonium oxalate. Filter and dissolve the precipitate in warm concentrated HCl. Make ammoniacal with $NH_4OH$ and white $Ce(OH)_3$ is formed. Upon oxidation with $H_2O_2$ its color is changed to reddish orange.

### Chlorine (Cl)

(1) *Flame Coloration with Copper Oxide.*—If a hot salt of phosphorus bead saturated with CuO is brought in contact with a chloride and then heated in the non-luminous flame, copper chloride will be formed which will tinge the flame azure blue. (Bromine gives a similar reaction.)

(2) *Liberation of Chlorine.*—If a chloride is mixed with $KHSO_4$ and a small amount of $MnO_2$ and then heated in a closed tube, free chlorine is set free. AgCl and silicates containing chlorine require fusion with $Na_2CO_3$.

(3) *Precipitation as Silver Chloride.*—A few drops of $AgNO_3$ added to a chloride in a dilute $HNO_3$ solution precipitates white curdy AgCl,

soluble in $NH_4OH$. This is an extremely delicate test. Minerals insoluble in $HNO_3$ should be fused with $Na_2CO_3$.

### Chromium (Cr)

(1) *Bead Tests.*—Chromium colors borax and microcosmic salt beads an emerald green, in both the oxidizing and reducing flames.

(2) *Fusion with Sodium Carbonate on Platinum Wire.*—When chromium compounds are dissolved in a $Na_2CO_3$ bead under the influence of the oxidizing flame, the fusion is colored a light yellow If instead of Pt wire, a charcoal support is used, a little $KNO_3$ should be added to the $Na_2CO_3$ to offset the reducing action of the support.

(3) *Precipitation as Lead Chromate.*—Fuse with $Na_2CO_3$ and $KNO_3$ on charcoal. Leach with water, make slightly acid with acetic acid, and add a few drops of lead acetate. A yellow precipitate of lead chromate will be formed.

(4) *Oxidation to Perchromic Acid.*—Dissolve the fusion in water and acidify with dilute $H_2SO_4$. To the cold solution add $H_2O_2$ and a blue color of $H_3CrO_8$ is obtained. Perchromic acid is very unstable and the color may last but a few seconds.

### Cobalt (Co)

(1) *Bead Tests.*—Cobalt imparts a blue color to the borax and salt of phosphorus beads, in both the oxidizing and reducing flames. When copper and nickel interfere, fuse the bead on charcoal with a particle of metallic tin. Cu and Ni are reduced to the metallic condition and the blue color of cobalt will appear.

### Columbium (Cb). See Niobium

### Copper (Cu)

(1) *Sublimate on Plaster Tablet.*—When moistened with HBr and heated on a plaster support copper minerals yield a volatile purplish coating, mottled with black.

(2) *Flame Test.*—Oxides of copper color the flame emerald green, while moistening with HCl produces an intense azure blue.

(3) *Bead Tests.*—Under the influence of the oxidizing flame borax and microcosmic salt beads are green when hot, and blue when cold. In the reducing flame $Cu_2O$ is formed which colors the beads on opaque red.

(4) *Reduction to Metal on Charcoal.*—When heated on charcoal with a mixture of $Na_2CO_3$ and borax, copper minerals yield globules of metallic copper. Sulphides should first be roasted before reducing.

(5) *Blue Solution with Ammonium Hydroxide.*—A copper solution made alkaline with $NH_4OH$ assumes a deep blue color.

### Fluorine (F)

(1) *Etching Glass Tube.*—When mixed with four or five parts of $KHSO_4$ or with sodium metaphosphate (obtained by fusing salt of phosphorus) and then heated in a closed tube many powdered fluorides liberate HF, which etches the glass near the assay. In addition a ring of $SiO_2$ may form in the upper part of the tube. The etching of the glass may be seen to best advantage by breaking the closed end of the tube, washing out its contents and drying the tube over a flame when the glass will appear clouded near the assay.

(2) *Flame Test.*—Fluorides mixed with $KHSO_4$ and borax and introduced into the Bunsen flame on a platinum wire give a flash of green due to the volatilization of $BF_3$.

### Glucinum (G); See Beryllium

### Gold (Au)

(1) *Sublimate on Plaster Per Se.*—Upon intense and prolonged ignition on the plaster support, gold gives a slight purple to rose colored coating near the assay. It is best seen when the tablet is cold.

(2) *Cassius Purple Test.*—Gold dissolves readily in nitro-hydrochloric acid (aqua regia) with the formation of auric chloride, $AuCl_3$. Evaporate the solution to dryness and dissolve the residue in a little water. If a few drops of stannous chloride are now added a finely divided precipitate will form which is purplish in transmitted and brownish in reflected light. This is known as the Cassius purple test for gold and is extremely delicate. The color is due to a mixture of colloidal gold and tin hydroxide. Ferrous salts also precipitate gold at ordinary temperatures from neutral or acid solutions (difference from platinum).

### Hydrogen (H)

(1) *Water in Closed Tube.*—When minerals containing water of crystallization or the hydroxyl radicle are heated in a closed tube, water is set free which condenses on the cold portions of the tube. More intense heat is necessary to liberate the hydroxyl radicle. The water which may be neutral towards test papers is often acid in reaction, but rarely alkaline.

### Iodine (I)

(1) *Heating with Potassium Bisulphate.*—Iodides when heated in a closed tube with $KHSO_4$ liberate violet vapors, often accompanied by a metallic sublimate of iodine.

(2) *Precipitation as Silver Iodide.*—A few drops of $AgNO_3$ added to an iodide in a dilute $HNO_3$ solution precipitates AgI, nearly insoluble in ammonia. (Distinction from Cl and Br.)

## Iron (Fe)

(1) *Magnetic upon Ignition.*—A few iron minerals (magnetite, pyrrhotite) are magnetic before heating, the majority become magnetic when heated in the reducing flame and allowed to cool. (Cobalt and nickel minerals react in a similar manner.)

(2) *Borax Bead Test.*—In the oxidizing flame iron colors the borax bead yellow when cold. In the reducing flame a pale green results.

(3) *Precipitation as Ferric Hydroxide.*—If an acid solution containing ferric iron is made ammoniacal with$NH_4OH$, a reddish brown precipitate of $Fe(OH)_3$ is formed. To obtain the iron in the ferric condition a few drops of $HNO_3$ should be added to the HCl when dissolving the mineral.

(4) *Test for Ferrous and Ferric Iron.*—If an iron mineral is dissolved in a non-oxidizing acid as HCl or $H_2SO_4$, the valence of the iron in solution will be the same as in the original mineral. If a few drops of potassium ferricyanide are added to a solution of ferrous iron, a dark blue precipitate will be formed. Ferric iron, on the other hand, gives a similar precipitate with potassium ferrocyanide. Potassium sulphocyanate, KCNS, gives a blood red color, but no precipitate, when added to a ferric solution.

## Lead (Pb)

(1) *Sublimate on Plaster Tablet.*—When mixed with bismuth flux and heated on a plaster support, lead minerals yield a chrome yellow coating. A drop of $(NH_4)_2S_x$ applied to the film gives a black spot.

(2) *Bismuth Flux on Charcoal.*—Upon charcoal lead minerals, mixed with bismuth flux, produce a greenish yellow film.

(3) *Reduction on Charcoal.*—Mixed with $Na_2CO_3$ on charcoal lead compounds give a yellow coating, and gray malleable globules.

(4) *Precipitation as Lead Sulphate.*—From a dilute $HNO_3$ solution lead may be precipitated as white insoluble $PbSO_4$, upon the addition of a few drops of $H_2SO_4$.

## Lithium (Li)

(1) *Flame Test.*—Lithium imparts a carmine red coloration to the flame. The color is not as persistent as that of strontium. If to a solution of a lithium salt a few drops of $BaCl_2$ are added, the red color (Li) will appear before the green of barium. (Strontium will appear after the green.) Lithium minerals do not become alkaline upon ignition

(difference from Sr). In testing silicates it is necessary to mix the assay with powdered gypsum and introduce it into the flame on a platinum wire.

### Magnesium (Mg)

(1) *Ignition with Cobalt Nitrate.*—Infusible and light colored magnesium minerals assume a pink color when moistened with a drop or two of cobalt nitrate and intensely ignited. This test is unsatisfactory at times and the following wet reaction must then be employed.

(2) *Precipitation as Ammonium Magnesium Phosphate.*—If hydrogen sodium phosphate, $Na_2HPO_4$, is added to a strongly ammoniacal solution, magnesium is precipitated as ammonium magnesium phosphate, $NH_4MgPO_4$. The precipitate is white and crystalline, and may appear only after shaking and standing for a short time. In order to remove interfering elements proceed as follows: The HCl solution containing a few drops of $HNO_3$ is boiled and then made alkaline with $NH_4OH$. This will precipitate Fe, Al, and Cr, if present. To the ammoniacal filtrate add ammonium oxalate to remove Ca, Ba, and Sr. To the filtrate $Na_2HPO_4$ is then added to test for magnesium.

### Manganese (Mn)

(1) *Borax Bead Test.*—Manganese colors the borax bead reddish violet in the oxidizing flame, but becomes colorless in the reducing flame. Salt of phosphorus gives a similar reaction but the test is not as sensitive.

(2) *Fusion with Sodium Carbonate on Platinum Wire.*—When dissolved in a $Na_2CO_3$ bead in the oxidizing flame, manganese compounds color the fusion a bluish green due to the formation of sodium manganate, $Na_2MnO_4$. If a charcoal support is used instead of platinum wire, a small amount of $KNO_3$ should be added to the $Na_2CO_3$ to offset the reducing action of the support.

(3) *Heating in Closed Tube.*—Some of the higher oxides yield oxygen, or when dissolved in HCl evolve chlorine.

(4) *Oxidation to Permanganic Acid.*—Boil with $HNO_3$ and $Pb_3O_4$ and allow the lead oxide to settle. The supernatant solution will be purplish from the permanganic acid formed.

### Mercury (Hg)

(1) *Sublimate on Plaster Tablet.*—When mixed with bismuth flux and heated on a plaster support, mercury minerals produce a coating which is usually a combination of scarlet, yellow, and greenish black.

(2) *Heating in a Closed Tube.*—When mixed with three parts of dry $Na_2CO_3$ and heated, metallic mercury will be volatilized and condensed as globules on the sides of the tube.

(3) *Precipitation by Copper.*—A clean copper wire immersed in a mercury solution becomes covered with a deposit of metallic mercury.

## Molybdenum (Mo)

(1) *Sublimate on Plaster and Charcoal.*—When heated *per se* with the oxidizing flame some molybdenum compounds yield $MoO_3$, which is yellow when hot and white when cold. When touched with the reducing flame the white coating is changed to a deep blue. If a charcoal support is used, a copper red sublimate will also be noted surrounding the assay which is best seen in reflected light.

(2) *Treatment with Concentrated Sulphuric Acid.*—If a molybdate is treated with a few drops of concentrated $H_2SO_4$ in a porcelain dish and evaporated almost to dryness, the mass upon cooling is colored intensely blue. The color will disappear upon the addition of water. Molybdenite ($MoS_2$) must be oxidized, either by boiling to dryness with $HNO_3$ or by roasting, before it can be tested in this manner.

(3) *Formation of Molybdenum Thiocyanate.*—KCNS causes little or no change when added to HCl solution of molybdenum, but if it is then treated with zinc or $SnCl_2$, a blood red coloration is produced. The reaction takes place in the presence of phosphoric acid (difference from iron). If $H_2O_2$ is added to the solution immediately after the red color has developed, the color disappears, returning as soon as the $H_2O_2$ has been reduced.

## Nickel (Ni)

(1) *Bead Tests.*—Nickel colors the borax bead in the oxidizing flame a reddish brown, while the salt of phosphorus bead is yellow.

(2) *Pale Blue Solution with Ammonium Hydroxide.*—A fairly concentrated acid solution of Ni will become pale blue upon adding an excess of $NH_4OH$. The color is not as dark a shade as that produced by copper.

(3) *Precipitation with Dimethylglyoxime.*—Dissolve the mineral in $HNO_3$ and make the solution alkaline with $NH_4OH$. Filter if necessary and to the filtrate add several cc. of an alcoholic solution of dimethylglyoxime. A scarlet precipitate indicates nickel.

## Niobium (Nb)

(1) *Reduction with Tin.* Finely powdered niobates are decomposed when heated to dull redness with $KHSO_4$ in a test tube. When decomposition is complete, rotate and incline the tube so that the melt may solidify as a thin crust on the sides. Add HCl, some metallic tin, and boil. Reduction takes place and a light blue color due to niobium will appear. The color becomes much fainter upon the addition of water.

### Nitrogen (N)

(1) *Heating in Closed Tube.*—Nitrates heated in a closed tube with $KHSO_4$ liberate reddish brown fumes of $NO_2$.

(2) *Brown Ring Test.*—Acidify the solution with a few cc. of dilute $H_2SO_4$, then add twice its volume of concentrated $H_2SO_4$. Cool and add fresh $FeSO_4$ solution so that it forms a separate layer on top. A brown ring will form at the junction of the two liquids. (Iodides give a ring of free iodine which interferes with the test.)

### Oxygen (O)

(1) *Heating in Closed Tube.*—Some of the higher oxides liberate oxygen which causes a glowing splinter to take fire.

(2) *Evolution of Chlorine.*—If HCl is added to some of the higher oxides, free chlorine is liberated which is recognized by its odor and bleaching properties.

### Phosphorus (P)

(1) *Reduction with Magnesium Ribbon.*—Phosphides of aluminum and the heavy metals should be fused with $Na_2CO_3$ and the powdered fusion ignited in a test tube with Mg ribbon. The phosphorus is converted into a phosphide which upon the addition of a few drops of water liberates phosphine, $PH_3$, recognized by its unpleasant garlic odor and ability to produce a black coloration when brought in contact with filter paper moistened with $AgNO_3$. Phosphates of the alkalies and alkaline earths may be ignited with Mg ribbon directly without previous fusion. This test is not satisfactory if arsenic or antimony are present.

(2) *Precipitation with Ammonium Molybdate.*—The phosphate is dissolved in $HNO_3$ (if insoluble, fusion with $Na_2CO_3$ should precede solution in acid) and a portion of the filtrate added to an excess of ammonium molybdate solution. Upon standing or slightly warming a yellow precipitate of ammonium phosphomolybdate will be formed.

### Platinum (Pt)

(1) *Brownish Red Solution with Potassium Iodide.*—Dissolve several scales of platinum in concentrated aqua regia and evaporate to dryness. Redissolve in HCl and evaporate to a thick paste. Dilute with water and then add a few drops of $H_2SO_4$ and a crystal of KI. The solution assumes a wine red color. This test will not detect traces of platinum in the presence of large quantities of iron.

(2) *Precipitation of Potassium Platinic Chloride.*—Add KCl to a portion of the paste obtained as indicated in (1). Yellow crystals of $K_2PtCl_6$, insoluble in alcohol, will be precipitated.

### Potassium (K)

(1) *Flame Test.*—Volatile potassium compounds impart a pale violet color to the non-luminous flame. If obscured by sodium, view the flame through a thick blue glass or a Merwin Color Screen. Through blue glass the flame appears purplish red, while through the Merwin screen the coloration is blue violet through division 1, and red violet through divisions 2 and 3. In testing silicates it will be necessary to mix the assay with powdered gypsum and introduce it into the flame on a platinum wire.

### Selenium (Se)

(1) *Sublimate on Plaster Tablet.*—When heated on the plaster tablet *per se*, selenium gives a coating which is cherry red to crimson in thin layers and nearly black in thick deposits. When volatilized the fumes are reddish and have the odor of rotten horse-radish.

(2) *Flame Test.*—When volatilized-selenium imparts an indigo blue coloration to the flame.

### Silicon (Si)

(1) *Salt of Phosphorus Bead.*—Silica does not dissolve readily in the salt of phosphorus bead but forms an insoluble translucent skeleton.

(2) *Gelatinization with Acid.*—Finely powdered silicates, which are completely soluble in $HNO_3$ or HCl, form a gelatinous mass of silicic acid when evaporated almost to dryness.

(3) *Fusion with Sodium Carbonate.*—Insoluble silicates should be fused with three to four parts of $Na_2CO_3$ and dissolved in HCl. Evaporate to complete dryness and redissolve the bases with fairly concentrated HCl. $SiO_2$ remains insoluble and may be removed by filtering the solution.

### Silver (Ag)

(1) *Reduction on Charcoal.*—When silver minerals are heated on charcoal with three parts of $Na_2CO_3$ they are readily reduced to malleable, metallic globules. If sulphur, arsenic, or antimony are present, roasting should precede reduction in order to volatilize these constituents.

(2) *Precipitation as Silver Chloride.*—If to a $HNO_3$ solution of a silver mineral a few drops of HCl are added, a white curdy precipitate of AgCl will be formed. This precipitate is soluble in ammonia.

### Sodium (Na)

(1) *Flame Test.*—Sodium imparts an intense and prolonged yellow color to the flame. The color is invisible through a thick dark blue glass

or the Merwin Screen. Silicates of sodium should be mixed with gypsum and introduced into the flame on a platinum wire.

### Strontium (Sr)

(1) *Flame Test.*—Strontium imparts a crimson color to the flame, which is more persistent than that of Li, and is invisible through division 1 of the Merwin screen (distinction from Ca). If a few drops of $BaCl_2$ are added to a solution of a Sr salt the red color (Sr) will appear after the green of Ba. (Li will appear before the green.)

(2) *Alkaline Reaction upon Ignition.*—With the exception of silicates and phosphates, strontium minerals give upon ignition an alkaline reaction with turmeric paper. (Distinction from Li.)

(3) *Precipitation as Strontium Sulphate.*—From a Sr bearing solution $SrSO_4$ is precipitated upon the addition of a few drops of dilute $H_2SO_4$. (Distinction from Li.)

### Sulphur (S)

When present as sulphides:

(1) *Heating in Open Tube.*—Powdered sulphides are oxidized when heated in an open tube. $SO_2$ is set free and is recognized by its pungent odor and acid reaction with litmus paper.

(2) *Heating in Closed Tube.*—When heated in a closed tube some sulphides liberate a portion of their sulphur which condenses as a dark red liquid when hot and changes to a crystalline yellow solid when cold.

(3) *Fusion with Sodium Carbonate.*—Fuse with three to four parts of $Na_2CO_3$ and place a portion of the fusion on a silver coin. Moisten with a few drops of water. A dark brown to black spot indicates sulphur, provided selenium and tellurium are absent. To another portion of the fusion placed in a watch glass, add several drops of water and a drop or two of freshly prepared sodium nitroferricyanide. An intense purple color is indicative of sulphur.

(4) *Oxidation with Nitric Acid.*—Hot concentrated $HNO_3$ oxidizes sulphides to sulphates, liberating some free sulphur which rises to the surface. A few drops of $BaCl_2$ added to the filtrate precipitates the sulphur as white $BaSO_4$.

When present as sulphates:

(5) *Fusion with Sodium Carbonate.*—Mix the sulphate with an equal volume of powdered charcoal and three volumes of $Na_2CO_3$. Fuse and test as indicated in (3).

(6) *Precipitation as Barium Sulphate.*—Sulphates soluble in HCl are precipitated as $BaSO_4$ upon the addition of $BaCl_2$.

### Tellurium (Te)

(1) *Sublimate on Plaster Tablet.*—Tellurides heated *per se* or with bismuth flux on a plaster support yield a purplish brown coating. A

drop of concentrated $H_2SO_4$ added to the film and gently heated forms a pink spot.

(2) *Sublimate on Charcoal.*—When heated on charcoal a white sublimate of $TeO_2$ is formed near the assay which resembles $Sb_2O_3$. The coating is volatile and when touched with the reducing flame it colors the flame a pale green.

(3) *Test with Concentrated Sulphuric Acid.*—When gently warmed with concentrated $H_2SO_4$ powdered tellurides produce a reddish violet solution. Too intense heat or the addition of water will cause the color to disappear.

### Tin (Sn)

(1) *Reduction on Charcoal.*—If fused with an equal volume of powdered charcoal and two volumes of $Na_2CO_3$, tin minerals are reduced, forming minute metallic globules. Upon prolonged ignition the tin is volatilized and deposits as a white coating of $SnO_2$. Add a drop of $Co(NO_3)_2$ to the coating and heat. A bluish green spot results.

(2) *Reduction by Hydrogen.*—Place a fragment of cassiterite ($SnO_2$) in contact with metallic zinc and add dilute HCl. $H_2$ is liberated and reduces the $SnO_2$. The mineral becomes coated with a thin layer of metallic tin.

### Titanium (Ti)

(1) *Reduction with Tin.*—After fusion with three volumes of $Na_2CO_3$, the titanium will dissolve in HCl forming $TiCl_4$. Upon boiling with metallic tin the titanium is reduced to $TiCl_3$, the solution assuming a violet color. If only a small amount of titanium is present test No. 2 should be employed.

(2) *Oxidation with Hydrogen Peroxide.*—Dissolve the $Na_2CO_3$ fusion in 1 : 1 $H_2SO_4$ and when cold add water and a few drops of $H_2O_2$. The solution is colored a pale yellow to orange red, depending upon the amount of Ti in the solution. This reaction depends upon the formation of $TiO_3 . x\ H_2O$ and is exceedingly delicate.

### Tungsten (W)

(1) *Reduction with Tin.*—After fusion with $Na_2CO_3$, the sodium tungstate is dissolved in hot water (niobates are insoluble in water). Filter if necessary and acidify the filtrate with HCl. An insoluble white precipitate of hydrated tungstic acid, $H_2WO_4.H_2O$, is formed in the cold, which upon boiling turns yellow ($H_2WO_4$). Upon adding metallic tin and boiling, a dark blue solution results which is due to a heavy precipitate ($WO_3 + WO_2$) held in suspension. Dilution with water will not

cause the color to disappear (Distinction from niobium). Prolonged reduction finally produces a brown color ($WO_2$).

### Uranium (U)

(1) *Salt of Phosphorus Bead.*—Uranium colors the salt of phosphorus bead a yellowish green in the oxidizing flame and a bright green in the reducing flame. In the borax bead uranium can not be distinguished from iron.

(2) *Precipitation as Potassium Uranate.*—Potassium ferrocyanide produces a brown precipitate $(UO_2)_2[Fe(CN)_6]$ in a slightly acid solution, which upon the addition of KOH is changed to the yellow potassium uranate, $K_2U_2O_7$ (Distinction from cupric ferrocyanide.) If iron is present proceed as follows: Dissolve the fusion in aqua regia. Make alkaline with $NH_4OH$ which will precipitate the Fe and U as $Fe(OH)_3$ and $(NH_4)_2U_2O_7$. Add $(NH_4)_2CO_3$ and shake, the uranium forms a soluble complex salt. Filter and acidify with HCl. Add $NH_2OH$ until alkaline and the uranium is precipitated free from iron. Test precipitate as indicated in (1).

### Vanadium (V)

(1) *Bead Tests.*—Vanadium can usually be detected by the bead colorations. In the borax bead the color is yellowish green in the oxidizing flame and emerald green in the reducing flame, while the microcosmic salt bead is colored light yellow and emerald green respectively.

(2) *Oxidation with Hydrogen Peroxide.*—If to an acid solution of a vanadate $H_2O_2$ is added, pervanadic acid, $HVO_4$, is formed which colors the solution a reddish brown. This is a very delicate reaction.

(3) *Reduction with zinc.*—Zinc in an acid medium causes reduction of vanadic acid so that the solution turns blue, then green, and finally violet. (This test is not as delicate as test No. 2.)

### Zinc (Zn)

(1) *Sublimate on Charcoal.*—When the finely powdered mineral is mixed with $Na_2CO_3$ and a small amount of charcoal, zinc is reduced and then quickly oxidized forming an oxide coating near the assay which is pale yellow when hot, white when cold. A drop of $Co(NO_3)_2$ added to the sublimate and heated produces a green spot.

(2) *Heating with Cobalt Nitrate.*—When moistened with a drop of cobalt nitrate and intensely ignited, infusible and light colored silicates of zinc usually assume a blue color. ZnO or minerals forming the oxide upon heating, such as $ZnCO_3$, become green.

## Zirconium (Zr)

(1) *Turmeric Paper Test.*—Fuse with $Na_2CO_3$ and dissolve in dilute HCl. Turmeric paper dipped in this solution and dried is colored reddish brown. (See boron.) It is well to compare the turmeric paper with another strip treated only with HCl and dried.

(2) *Precipitation as Phosphate in Acid Solution.*—Dissolve the $Na_2CO_3$ fusion in HCl, boil, and filter. To the acid filtrate add several drops of $Na_2HPO_4$ and a white precipitate of zirconium phosphate will be formed. (Titanium is likewise precipitated under similar conditions.)

# CHAPTER XIV

## DESCRIPTIVE MINERALOGY

### INTRODUCTION

Descriptive mineralogy includes a detailed discussion in some systematic order of the crystallographic, physical, and chemical properties of minerals. Characterizing features, associations, occurrences, and uses are also given. Two general methods of classification of minerals are in common use. In one of these methods, all minerals possessing some element as an important constituent are grouped together irrespective of their chemical and crystallographic relationships. Thus, the important iron minerals would be grouped together, as follows:

| | | | |
|---|---|---|---|
| 1. Pyrrhotite, | FeS | 4. Magnetite, | $Fe(FeO_2)_2$ |
| 2. Pyrite, | $FeS_2$ | 5. Limonite, | $Fe_2O_3 \cdot H_2O$, |
| 3. Hematite, | $Fe_2O_3$ | 6. Siderite, | $FeCO_3$ |

The second method of classification is considered more scientific, and is followed in this text, the minerals being grouped according to their chemical composition and the principle of isomorphism. Minerals with the simplest composition are discussed first, while those of greatest complexity are treated last. Nine classes are easily arranged.

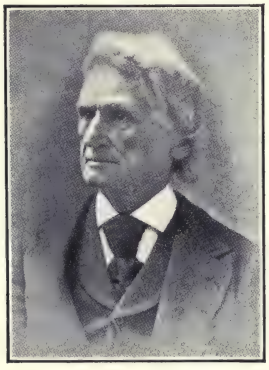


FIG. 393.—James D. Dana (1813–1895). Professor in Yale University (1850–1890). Author of "System of Mineralogy," the standard reference work on descriptive mineralogy.

1. Elements.
2. Sulphides, arsenides, sulpho-minerals.
3. Oxides, hydroxides.
4. Haloids.
5. Nitrates, carbonates, manganites.
6. Sulphates, chromates, molybdates, tungstates, uranates.
7. Aluminates, borates, ferrites.
8. Phosphates, vanadates.
9. Silicates, titanates.

Within each of these classes the various minerals are arranged, as far as possible, in isomorphous series, thus bringing together those minerals with analogous chemical compositions and strikingly similar crystal forms. In all, one hundred fifty minerals are described. The one hundred minerals, which are considered as the most important are designated by large, heavy type, thus **QUARTZ.** For the remaining

fifty minerals smaller type is used, thus **Scheelite.** In describing the individual minerals, the following order is used: a, *Name and formula;* b, *Crystallographic features and structure;* c, *Important physical properties, such as cleavage, fracture, hardness, specific gravity, luster, color, etc.;* d, *Chemical composition and properties;* e, *Varieties, if important;* f, *Occurrence, associations, and important localities;* g, *Uses.*

FIG. 394.—Alfred Lacroix (1863 —). Professor of mineralogy in the Muséum d' Historie Naturelle de France, Paris (1893 —). Authority on the minerals of France.

## I. ELEMENTS

Of the eighty and more known elements, only the following nine occur uncombined in nature in sufficient quantities to warrant description:

| | |
|---|---|
| NON-METALS | |
| **DIAMOND, C** | Cubic |
| **GRAPHITE, C** | Hexagonal |
| **SULPHUR, S** | Orthorhombic |
| SEMI-METALS | |
| ARSENIC GROUP | |
| **Arsenic, As** | Hexagonal |
| **Bismuth, Bi** | Hexagonal |
| METALS | |
| **PLATINUM, Pt** | Cubic |
| COPPER GROUP | |
| **COPPER, Cu** | Cubic |
| **SILVER, Ag** | Cubic |
| **GOLD Au** | Cubic |

The specific gravities of the non-metals are low, those of the semi-metals range from 5.6 to 10, while those of the metals may be as high as 22. The metals are malleable and ductile.

## Non-metals

The three minerals to be described here are of great value in commerce and industry.

**DIAMOND**, *Bortz, Carbonado,* **C.**

Cubic, probably hexoctahedral class. Usually in crystals or crystal fragments, microscopically small or over 3,000 carats* in weight. Most common forms are the octahedron (Fig. 395), rhombic dodecahedron, and hexoctahedron; rarer, the cube. Crystals are often rounded and distorted. Contact twins according to the Spinel law, the twinning plane being parallel to a face of the octahedron, are frequently noted. Sometimes massive.

Highly perfect octahedral cleavage. Hardness, 10 (hardest known mineral). Specific gravity, 3.15 to 3.53. Greasy adamantine luster (carbonado, dull). Commonly colorless, or slightly yellowish; also yellow, red, green, blue; more rarely black. Transparent to translucent and opaque. Very high index of refraction ($n_{B\ line}$ = 2.407, $n_{D\ line}$ = 2.417, $n_{H\ line}$ = 2.465). The *fire* so characteristic of the diamond is due to the exceptionally strong dispersion (2.465 − 2.407 = 0.058). Transparent to X-rays, while lead glass imitations, such as *paste* and *strass*, are not. Some diamonds phosphoresce after exposure to light or electric discharges.

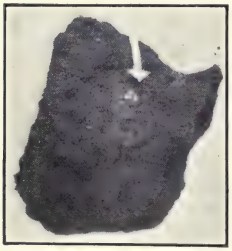


FIG. 395.—Diamond in blue ground. Kimberley, South Africa.

Colorless diamonds are pure carbon, for on combustion in an atmosphere of oxygen only carbon dioxide is obtained. Colored stones yield small residues. Unaffected by acids. Inclusions, especially of carbonaceous matter, are frequent.

There are three varieties of the diamond, (1) *Diamond proper,* (2) *Bortz* or *bort,* and (3) *Carbonado.*

1. *Diamond Proper.*—This variety has been known from the earliest times, and was called *adamas* by the ancients. These older stones were obtained from secondary deposits in eastern and southern India, which localities furnished some of the world's famous diamonds, but their output at present is very small.

According to tradition, diamonds were first discovered in the gold washings in Brazil in 1670, but not positively identified as such until 1721. The provinces of Minas Geræs and Bahia are the most important producers. Here also diamonds occur in stream sands and gravels.

The most important locality, yielding at present about 95 per cent. of the world's production, is South Africa where diamonds were discovered in 1867 on the south shore of the Orange river near Hopetown.

* The metric carat is 200 milligrams, and has been in use in the United States since July 1, 1913.

At first, they were found in the "river diggings," that is, in the sands and gravels of the streams, especially the Orange, Vaal, and Modder rivers. About three years later, diamonds were discovered in primary deposits, known as "dry diggings," upon the plateau between the Vaal and Modder rivers. Here the occurrence of the diamond is restricted to limited areas, elliptical or circular in outline, and varying from 20 to 700 and more meters in diameter (Figs. 396 and 397). On the surface the diamonds were found in a soft, decomposed material known as the *yellow ground*. At depth the diamond-bearing areas constrict, and the yellow ground is underlaid by a hard basic magnesian rock, known as kimberlite or the *blue ground*. These areas are volcanic pipes. Originally the diamonds were easily recovered from the soft yellow ground by simply washing away the lighter constituents, and sorting the diamonds from the concentrates. But now, the harder blue ground is brought to the surface in large lumps and generally exposed in the open fields, "depositing floors," to the action of the atmospheric agencies. In due time the material crushes very easily, and is then washed and concentrated. These concentrates are passed over oscillating tables covered with grease, called "sorters or pulsators." Of all the minerals in the concentrates the diamond is the only one which will stick to the grease, from which it is easily recovered at intervals. At the Premier mine the blue ground is crushed and concentrated immediately after being mined.

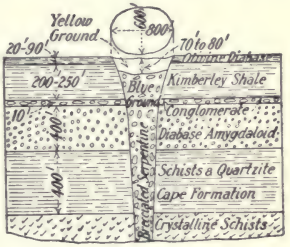



FIG. 396.—Section through the Kimberley Mine.

FIG. 397.—Kimberley Open Diamond Mine, Depth 1000 feet.

Kimberley is the diamond center for South Africa, four important mines, the Kimberley, Du Toitspan, De Beers, and Bultfontein, being located in its immediate vicinity. Other important mines are the Jagersfontein, in the Orange Free State, and the Premier in the Transvaal, near Pretoria. The Premier is the largest known diamond mine and covers about eighty acres. Diamonds also occur in secondary deposits near Lüderitz Bay on the west coast of Africa, and along the Kasai river in the Belgian Congo. In 1913 the various African localities produced over 5¾ million carats of diamonds valued at about $45,000,000.

Diamonds have also been found in Australia, Ural Mountains, British Guiana, Columbia, Mexico, and British Columbia. In the United States

occasional diamonds have been discovered in Wisconsin, Indiana, Michigan, California, Georgia, and North Carolina. The most important find of diamonds in the United States was made on August 1, 1906, near Murfreesboro, Pike County, Arkansas. The occurrence here is strikingly similar to that of the principal South African localities, and up to July 1, 1916, more than 4,500 stones have been recovered.

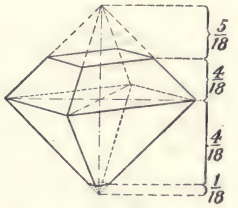



FIG. 398.

FIG. 399.

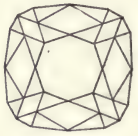


FIG. 400.

Microscopic diamonds have been found in meteorites (Canon Diablo, Arizona) and in certain types of steel and cast iron.

The diamond has long been used as a gem, but the ancients were content to polish the natural crystal faces. In 1456 the art of cutting facets on the diamond was invented whereby the *fire* was greatly in-

FIG. 401.—Cullinan Diamond. Premier Mine, South Africa. Weight 3,106 carats.

creased. Many different styles of cutting have been in use at various times, but at present the *brilliant* cutting is the most common. As illustrated in Fig. 398, the octahedron, either natural or obtained by cleavage, is made the basis for this style of cutting. Figures 399 and 400 are side and top views of the cut stones. Usually there are 58 facets,

but in some cases as high as 74 are cut. Depending upon the character of the rough stone, from a third to one-half of its weight is lost in cutting Amsterdam and Antwerp are the most important diamond cutting centers. See also pages 329 to 338.

The largest diamond ever found was the *Cullinan* or *Premier*, also called the "*Star of Africa*," discovered on January 25, 1905, at the Pre-

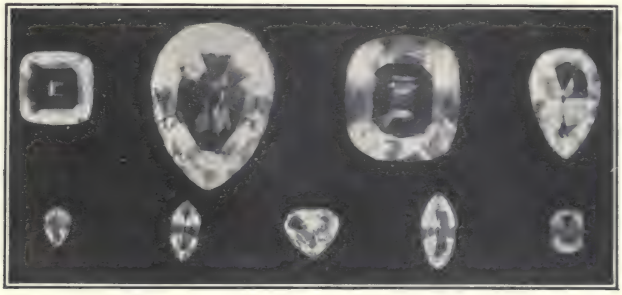


FIG. 402.—The nine largest stones cut from the Cullinan Diamond.

mier mine, in the Transvaal (Fig. 401). This stone weighed 621.2 grams or 3,106 carats. It measured about $10 \times 6.5 \times 5$ centimeters, and was a cleavage fragment of a larger stone. It was purchased by the Assembly of Transvaal and presented to King Edward VII and subsequently cut into 9 larger (Fig. 402) and 96 smaller stones. The two largest stones are called *Cullinan I* and *II*, and weigh 530.2 and 317.4 carats, respectively. Some of the other famous cut diamonds and their

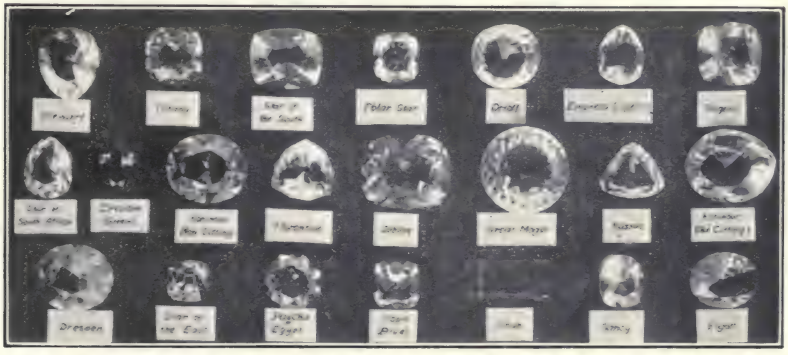


FIG. 403.—Photograph of glass models of famous large diamonds.

approximate weights are: the *Jubilee*, 245.3 carats; *Kohinoor*, 106 carats; *Orloff*, 195 carats; *Regent*, 137 carats; *Tiffany* (yellow), 128.5 carats; *Hope* (blue), 44.5 carats; *Dresden* (green), 40 carats; *Star of the South*, 125.5 carats (Fig. 403).

(2) *Bortz.*—Also called bort and boart. Dark colored, poorly crystallized variety, often with a radial fibrous structure. Translucent to

opaque. Crystals and fragments of an inferior quality, hence, unfit for gem purposes, are also called bortz.

(3) *Carbonado.*—Often called *black diamond,* or simply *carbon.* This variety is compact, opaque, and usually black to gray in color (Fig. 404). Specific gravity, 3.15 to 3.29. No cleavage. Found in placer deposits in the Province of Bahia, Brazil. The largest carbonado ever found weighed 3,078 carats.

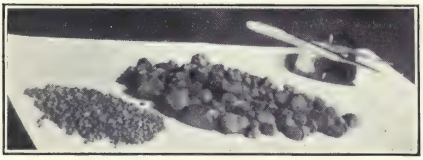


FIG. 404.—Carbonado. Brazil.

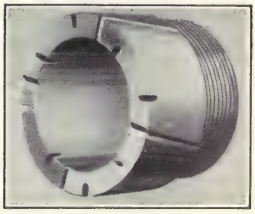


FIG. 405.—Diamond drill bit.

*Diamond proper* is used extensively as a gem. Inferior stones and *bortz* are used as an abrasive, glass cutters, and as dies for wire-drawing. *Carbonado,* broken into small cubes, is used in diamond drilling, the small cubes being set in the bit (Fig. 405). Diamond drilling is used extensively to determine the location and size of ore bodies and the character of the rocks to be penetrated and, hence, is of the utmost importance in mining and structural engineering.

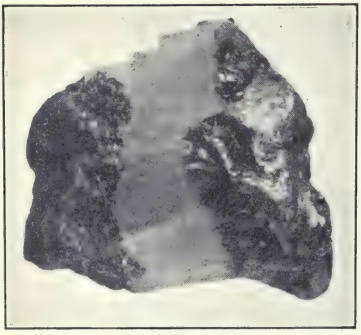


FIG. 406.—Graphite with calcite. Ticonderoga, New York.

**GRAPHITE** (*Plumbago, Black Lead*), **C.** Hexagonal, ditrigonal scalenohedral class. Crystals are small, tabular, and hexagonal in outline, but very rare. Usually found in foliated, scaly, granular and compact, or earthy masses (Fig. 406).

Perfect basal cleavage, yielding very thin and flexible laminæ. Hardness 1 to 2, marks paper and soils the fingers. Greasy feel. Specific gravity 1.9 to 2.3. Iron black to dark gray in color. Shiny black streak. (Rubbed streak black; molybdenite, greenish.) Opaque. Metallic luster, sometimes dull or earthy. Good conductor of electricity. Transparent to the X-rays.

Essentially carbon, but not as pure as the diamond. On combustion may yield as much as 20 per cent. ash. Not attacked by acids. Graphite brought in contact with metallic zinc in a solution of copper sulphate is quickly copper plated, while molybdenite treated in the same way is only slowly coated. Infusible.

Graphite occurs in large masses and disseminated scales, also in dikes and veins in granites, gneisses, mica schists, and crystalline limestones. In some cases it is the result of metamorphic action on carbonaceous matter, as in Rhode Island, or it may be due to the reduction of carburetted vapors, as in Ceylon, or of the oxides of carbon, as at Ticonderoga and vicinity in the eastern part of New York State. Common associates are calcite, orthoclase, quartz, pyroxene, garnet, spinel, and amphibole. The principle sources are: Ceylon; Madagascar; Chosen (Korea); Sonora, Mexico; Austria; eastern New York; Chester County, Pennsylvania; Clay County, Alabama; and Dillon, Montana.

Artificial graphite is now manufactured in large quantities from anthracite coal or petroleum coke in the electric furnace at Niagara Falls, New York. In 1913 over 6,800 tons of artificial graphite were produced.

Graphite is used extensively in the manufacture of crucibles, stove polish, foundry facings, lead pencils, paint, lubricants, and electrodes.

**SULPHUR** (*Brimstone*), **S.**

Orthorhombic, bipyramidal class. Crystals are common, showing mostly pyramidal or tabular habits, Figs. 407 and 408. Also in granular, fibrous, earthy powdery, or stalactitic masses (Fig. 409).

FIG. 407.

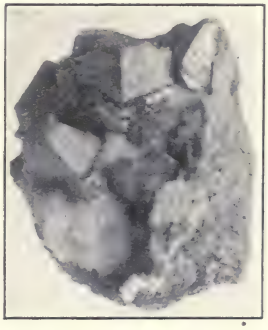


FIG. 408.—Sulphur with calcite. Racalmuto, Sicily.

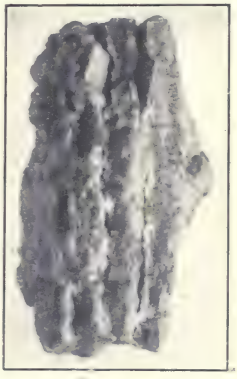


FIG. 409.—Banded sulphur in limestone. Racalmuto, Sicily.

Indistinct cleavages. Pronounced conchoidal to uneven fracture. Hardness 1.5 to 2.5. Specific gravity, 1.9 to 2.1. Adamantine luster on crystal faces, otherwise resinous to greasy. Transparent to translucent. White to yellow streak. Usually sulphur yellow in color; also honey-yellow, or yellow brown, and due to impurities, reddish, greenish, or grayish. Non-conductor of electricity and heat. On account of the low conductivity and unequal distribution of heat, cold

crystals often crack when held in the hand. When held to the ear a crackling sound may be heard.

Usually practically pure sulphur; sometimes mixed with bitumen and clay. Melts at 114.5° C., and at 270° C. burns with a bluish flame to sulphur dioxide. Insoluble in water and acids. Soluble in carbon disulphide.

The large and commercially important deposits occur in sedimentary rocks and are generally the result of the reduction of sulphate minerals, notably gypsum. The common associates are celestite, gypsum, aragonite, and calcite. In the United States, important producing localities are near Lake Charles in southwestern Louisiana, and at Freeport, Texas. Here by means of superheated water and compressed air the sulphur is pumped to the surface in a molten condition, and allowed to solidify in large vats. It is then ready for shipment, being 99.5 per cent. pure sulphur. Girgenti, Sicily, has for many years been the chief center of the sulphur industry of Sicily. Sulphur is found in small quantities around volcanoes, the result of sublimation or interaction of sulphurous vapors; thus, on Mounts Vesuvius and Ætna, also in Iceland, Japan, and Hawaii. It occurs also as the result of deposition from certain hot springs, and from the decomposition of pyrite and other sulphide minerals.

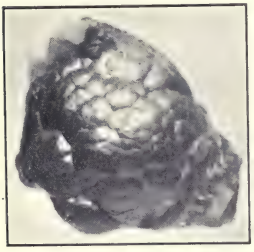


FIG. 410.—Arsenic. Andreasberg, Germany.

Important in the manufacture of sulphuric acid, matches, gunpowder, vulcanized rubber, insecticides, medicines, the bleaching of silk, straw, and woolen materials, and in the preparation of wood pulp used in the manufacture of paper.

## Semi-metals—Arsenic Group

The members of this group crystallize in the hexagonal system in pseudo-cubical rhombohedrons. They are brittle and non-malleable.

**Arsenic** (*Native Arsenic*), **As.**

Hexagonal, ditrigonal scalenohedral class. Crystals are pseudo-cubical rhombohedrons, but very rare. Commonly in compact, scaly, granular, or fine grained masses with reniform and botryoidal structures (Fig. 410). Often breaks into concentric or onion-like layers.

Basal cleavage, but usually not conspicuous. Uneven and fine grained fracture. Hardness 3 to 4. Specific gravity 5.6 to 5.8. Metallic luster. Opaque. Tin-white color on fresh fracture surface, tarnishes dark gray to black on exposure. Grayish streak.

Arsenic, often contains antimony; also bismuth, cobalt, nickel, silver, iron, or gold.

Found principally in veins with silver, cobalt, and nickel ores; thus in the Freiberg mining district of Saxony; Joachimsthal, Bohemia; Kongsberg, Norway; Mexico; Chile.

Native arsenic furnishes but a small portion of the arsenic used in commerce and industry. Artificial metallic arsenic is a constituent of shot metal.

**Bismuth** (*Native Bismuth*), **Bi.**

Hexagonal, ditrigonal scalenohedral class. Rarely in rhombohedral crystals. Usually in compact, reticulated, arborescent, platy, or compact masses (Fig. 411).

Basal cleavage, generally conspicuous. Hardness 2 to 2.5. Specific gravity 9.7. Brittle, slightly malleable when heated. Metallic luster. Opaque. Reddish white color, often with brassy tarnish colors. Shiny lead gray streak.

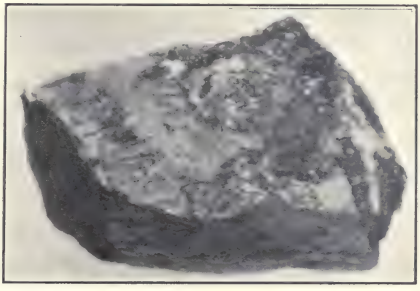


FIG. 411.—Bismuth with calcite and smaltite. Cobalt, Ontario.

Bismuth, often with traces of arsenic, sulphur, and tellurium.

Not especially abundant, but usually in veins associated with silver, cobalt, lead, zinc, and tin ores. Important localities are: Freiberg, Saxony; Joachimsthal, Bohemia; Bolivia; Cornwall, England; Cobalt, Ontario.

Native bismuth is a source of the metal and its compounds. The metal is used in the manufacture of easily fusible alloys, such as find application in automatic sprinklers and safety plugs in boilers; also in rifle bullets and thermo piles. The salts of bismuth are used in medicine, calico printing, and in the manufacture of highly refractive glass.

## Metals

Only the four very important elements platinum, copper, silver, and gold will be described.

**PLATINUM** (*Native Platinum*), **Pt.**

Cubic, hexoctahedral class. Small crystals, generally cubes, but very rare. Usually in scales or grains; also in nuggets.

Hackly fracture. Metallic luster. Opaque. Hardness 4 to 6. Specific gravity 14 to 19; melted platinum is 19.7, hammered 21.23. Malleable, ductile, sectile. Silver white to dark gray or black in color. May be magnetic if much iron is present.

Platinum, usually contains iron (up to 19.5 per cent.), and smaller amounts of iridium, rhodium, palladium, osmium, copper, and at times gold. Infusible at ordinary temperatures, but may be fused and welded with the oxyhydrogen blowpipe. Soluble in hot concentrated nitro-hydrochloric acid.

Platinum was first discovered in 1735 in the gold placers of the Pinto river in Colombia, associated with gold, zircon, magnetite, chromite and so forth. In 1822 it was found in the alluvial deposits of Nizhni Tagilsk in the Ural Mountains. Although practically all of the world's supply is obtained from placer deposits, platinum also occurs in veins associated with chromite and disseminated in peridotite rocks. Russia is the chief producer and controls the market. In the United States small amounts are found in the black sands of the rivers along the Pacific coast. Important occurrences in veins and disseminated have been recently discovered near Bunkerville, Clark County, Nevada, and in Westphalia, Germany.

Platinum is used very extensively in the manufacture of sulphuric acid (contact method) and in physical, chemical, and electrical apparatus; also in jewelry, pyrography, dentistry, non-magnetic watches, and surgical instruments. It was worth $.35 a gram in 1895, $.70 in 1901, $1.10 in 1910, $1.50 in 1913, $2.75 in 1916, $5.55 in 1918, and $3.90, July, 1920.

## Copper Group

The very important metals copper, silver, and gold belong to this group. They crystallize in the cubic system, are rather soft, heavy, and very malleable.

**COPPER** (*Native Copper*), **Cu.**

Cubic, hexoctahedral class. Crystals are rather common, but usually distorted and in parallel groups. Tetrahexahedrons, rhombic dodecahedron, and cube are the most commonly observed forms (Figs. 412, 413, and 414). Generally in scales, grains, plates, and masses, oftentimes weighing many tons; less frequently arborescent and filiform.

Hackly fracture. Hardness 2.5 to 3. Specific gravity 8.5 to 9. Metallic luster. Ductile and malleable. Color copper-red on fresh fracture. Due to tarnish and decomposition products, color may be superficially black (CuO), red ($Cu_2O$), green ($CuCO_3.Cu(OH)_2$), or blue ($2CuCO_3.Cu(OH)_2$). Streak copper red, metallic and shiny. Excellent conductor of heat and electricity.

Generally almost pure copper; sometimes contains small amounts of silver or arsenic.

The most important locality for the occurrence of native copper is Keweenaw Peninsula in Northern Michigan, where it occurs disseminated, principally in fine grains or scales, or in veins in (1) dark colored

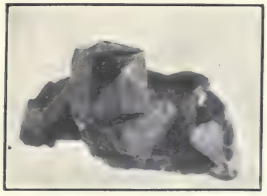


FIG. 412.—Crystallized copper (tetrahexahedron). Phoenix Mine, Lake Superior District.

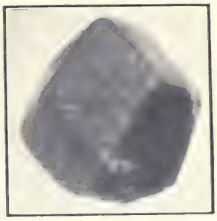


FIG. 413.—Crystallized copper (rhombic dodecahedron). Lake Superior District.

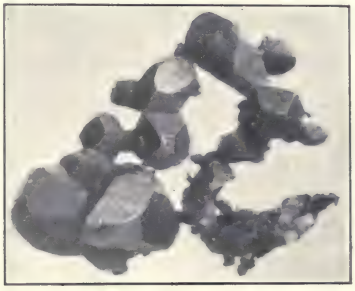


FIG. 414.—Crystallized copper. Lake Superior District.

igneous rocks, called melaphyr amygdaloids (Figs. 415 and 416), (2) in reddish quartz porphyry coñglomerates (Fig. 417); (3) in sandstones; (4) in epidotic beds; (5) in felsitic rocks. The first two occurrences are at

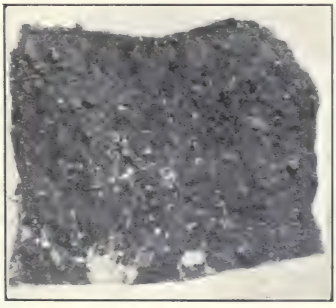


FIG. 415.—Copper in amygdaloid. Lake Superior District.

FIG. 416.—"Shot" copper. Adventure Mine, Lake Superior District.

present the most important. These ores average about 1 per cent. of copper and are easy to treat. By means of crushing, washing, and concentrating with jigs and tables the metallic copper is readily extracted. It is then smelted and refined, and cast into ingots and sold as "lake"

copper. In 1915 this district produced 241,951,921 pounds. About 80 per cent. of the ore handled was amygdaloid rock. The common associates are calcite, quartz (Fig. 418), datolite (Fig. 419), epidote, silver, analcite, and other zeolites.

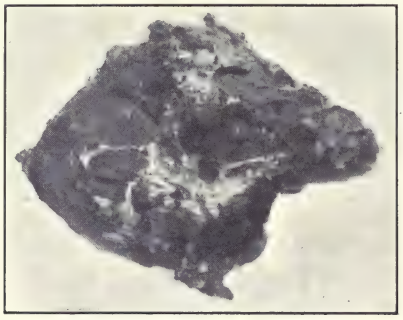


FIG. 417.—Copper conglomerate. Lake Superior District.

Native copper also occurs in smaller quantities associated with the other copper minerals—malachite, azurite, cuprite, chalcopyrite, bornite, and chalcocite—especially in Arizona and New Mexico.

Metallic copper is used very extensively in commerce and industry. Large amounts are used in the manufacture of copper wire, nails, and

FIG. 418.—Copper with calcite and quartz. Lake Superior District.

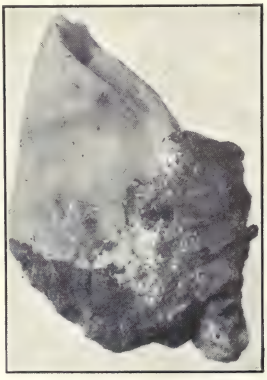


FIG. 419.—Copper with datolite (white). Lake Superior District.

sheets, brass, bronze, electrical apparatus, munitions of war; also for coinage purposes and chemical reagents. It is said that there are about 600 uses for copper where it is practically indispensable. The price of metallic copper fluctuates greatly, in 1912 it averaged about 16 cents a pound, in 1913 about 15 cents, in 1914 about 13 cents, in 1915 about 17.25 cents, in 1918 about 25 cents, and in July, 1920 about 19 cents.

**SILVER** (*Native Silver*), **Ag**.

Cubic, hexoctahedral class. Crystals usually small and distorted, and in parallel groups. Cubes and octahedrons most common. Also acicular, reticulated, or arborescent; fine threads or wires (Figs. 420 and 421), sometimes matted and resembling tufts or wads of hair; scales, plates, or large masses.

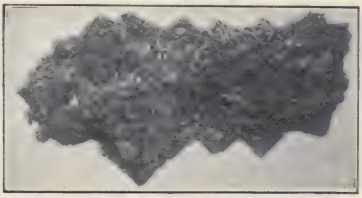


FIG. 420.—"Wire" silver with argentite. Porco, Bolivia.

FIG. 421.—"Wire" silver. Cliff Mine, Lake Superior District.

Malleable and ductile. Hardness 2.5 to 3. Specific gravity 10 to 12. Metallic luster. Color silver white, usually with yellow brown, gray, or black tarnish colors. Silver white streak, shiny. Excellent conductor of heat and electricity.

FIG. 422.—Silver (white) and copper "Half Breed." Lake Superior District.

FIG. 423.—Silver with calcite. La-Rose Mine, Cobalt, Ontario.

Silver, often with varying amounts of gold, up to 28 per cent.; also with copper, arsenic, antimony, mercury, iron, and platinum.

Occurs commonly with ores of silver, lead, copper, arsenic, cobalt and nickel, associated with calcite, quartz, barite, or fluorite. Kongsberg,

Norway, has furnished a great deal of silver in the form of crystals and large masses, some weighing 750 pounds. The Saxon mines at Freiberg, Marienberg, and Annaberg have long been heavy producers; also Mexico, especially Sonora, Durango, Sinaloa; Chile; Peru; and Bolivia Several of the more important localities in the United States are: Bingham and Tintic districts, Utah; Butte, Montana (from copper ores); Tonopah, Nevada; Coeur d'Alene, Idaho; Aspen, Colorado; Lake Superior copper district, associated with copper, forming "half-breeds" (Fig. 422). In large deposits, disseminated and in veins, at Cobalt, Ontario, associated with niccolite, smaltite, erythrite, annabergite, bismuth, and calcite (Fig. 423). Many masses from this locality were 95 per cent. silver and weighed from 600 to 1,000 pounds. Rarely found as nuggets.

Native silver is used for coinage, jewelry, and ornamental purposes; also in physical, chemical, and surgical apparatus. The price varies greatly, and is, July, 1920, about $1.00 an ounce.

**GOLD** (*Native Gold*), **Au.**

Cubic, hexoctahedral class. Crystals are small, more or less distorted, but only rarely found. The most common forms are the octahedron, cube, and rhombic dodecahedron, occurring either independently or in combination. Skeletal development frequent. Usually in disseminated or rolled scales or grains; also filiform, recticulated, and in large lumps or nuggets (Fig. 424).

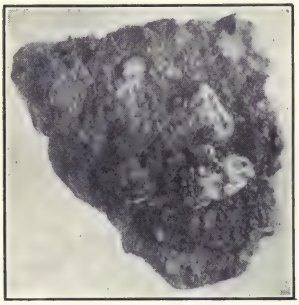


FIG. 424.—Gold in conglomerate. Western Sonora, Mexico.

Malleable and ductile. No cleavage, hackly fracture. Hardness 2.5 to 3. Specific gravity 15.6 to 19.3. Metallic luster. Golden to brassy or light yellow in color depending upon the amount of silver present. Opaque.

Gold, with varying amounts of silver (up to 40 per cent.); also iron, copper, bismuth, and so forth. Readily fusible and soluble in nitro-hydrochloric acid. Readily acted upon by chlorine, and potassium or sodium cyanide. Forms an amalgam with mercury.

Gold occurs widely distributed, but in only a comparatively few places in sufficient quantities to be of economic importance. There are two general types of occurrence, namely: (1) *in situ*, and (2) in *secondary deposits*, called *placers*.

Gold occurring *in situ* is usually found disseminated in quartz veins, and associated with various sulphide minerals, of which pyrite is the most important. Owing to the decomposition of the associated sulphides, the quartz, where exposed on the surface to the action of percolating water—zone of oxidation—is usually more or less cellular and of a rusty

appearance. Such quartz is often called "porous" or "rusty" quartz. Gold is also found disseminated in granites, trachytes, andesites, crystalline schists, sandstones, and conglomerates. The most common associates, aside from quartz and pyrite, are chalcopyrite, galena, stibnite, tetrahedrite, sphalerite, and arsenopyrite, some of which are frequently auriferous (Figs. 425 and 426).

*Free milling gold* is usually present in distinctly visible particles and is easily recovered by crushing and washing in a stamp mill and subsequent amalgamation with mercury, the finely crushed material from the mill being allowed to flow over copper plates coated with mercury. Where the gold is associated with considerable quantities of the sulphides, the chlorination or cyanide processes are used, either alone or in connection with amalgamation. In the chlorination process the auriferous ores are roasted and then subjected to the action of chlorine which causes

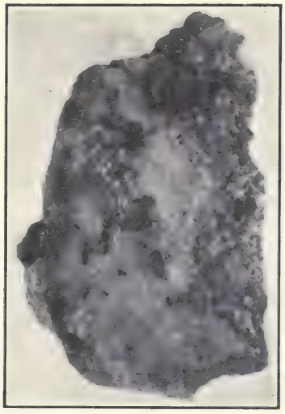


FIG. 425.—Gold in quartz. Tuolumne County, California.

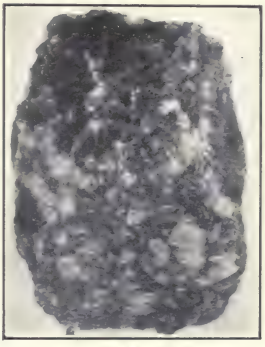


FIG. 426.—Gold bearing conglomerate. Rand Mines, Transvaal.

the gold to pass into solution. In the cyanide process the crushed ores, either raw or roasted, are treated with solutions of potassium or sodium cyanide, whereby a soluble double cyanide is formed. By means of electrolysis the gold is generally separated from these solutions. These processes permit ores carrying very small amounts of gold, sometimes as low as $1.50 per ton, to be worked with a profit.

Important localities for the occurrence of gold *in situ* are: California, Nevada, South Dakota, Utah, Alaska; the Rand in the Transvaal, South Africa; Western Australia, New South Wales, Ural Mountains; Porcupine district, Ontario.

*Placer* gold is the result of the disintegration of rocks containing gold *in situ*, that is, disseminated or in veins. As these rocks are reduced by the action of the atmospheric agencies and erosion to sand and gravel,

the gold, on account of its very high specific gravity, becomes concentrated in the stream beds in auriferous regions, and is found as scales, grains, and nuggets. Especially rich deposits are likely to be found where the velocity of the stream has been checked by a bend in its course or by some obstruction. Placer gold is readily recovered by washing, the sand and gravel being thrown into long wooden troughs called sluices. Through these sluices water flows at a rather rapid rate in order to carry away the lighter rock material. At regular intervals cross-bars, called riffles, are placed in the trough to check the velocity of the water. This causes the heavy particles to fall to the bottom of the sluices, and since mercury is added from time to time and is also caught by the riffles, an amalgam of gold is formed. From this amalgam the gold is easily recovered by volatilizing the mercury. In some localities *hydraulic* mining is employed in working placer deposits. This does not differ essentially from the above method and consists in directing a large stream of water under high pressure against the bank of the placer in order to loosen the same and wash the sand and gravel down into the sluices. This type of working placers is practicable only where there is an abundant water-supply. In regions where the supply of water is limited, dredges are used to advantage.

Gold placers are common in California, Alaska, Colorado, Australia, and Siberia. In practically all noteworthy gold producing districts, gold has usually been found first in placers, and by subsequent exploration the primary occurrences *in situ* have been located.

Gold is used chiefly for coinage and jewelry. Gold coins of the United States consist of nine parts of gold and one of copper. For jewelry purposes copper and silver are alloyed with gold to increase its hardness. The gold content of such alloys is expressed in carats, thus 14 carat gold consists of $^{14}\!/_{24}$ths gold and $^{10}\!/_{24}$ths other metals.

### 2. SULPHIDES, ARSENIDES, AND SULPHO-MINERALS

This group, consisting of twenty-three members, includes some of the most important ore minerals.

#### (*a*) Sulphides and Arsenides

| | | |
|---|---|---|
| **REALGAR** | **AsS** | Monoclinic |
| **ORPIMENT** | **$As_2S_3$** | Monoclinic |
| **STIBNITE** | **$Sb_2S_3$** | Orthorhombic |
| **Molybdenite** | **$MoS_2$** | Hexagonal |

Sphalerite-pyrrhotite Groups

| | | |
|---|---|---|
| **SPHALERITE** | **ZnS** | Cubic |
| **PYRRHOTITE** | **FeS** | Hexagonal |
| **Niccolite** | **NiAs** | Hexagonal |

PYRITE-MARCASITE GROUPS

| | | |
|---|---|---|
| **PYRITE** | $FeS_2$ | Cubic |
| **Cobaltite** | $CoAsS$ | Cubic |
| **Smaltite** | $CoAs_2$ | Cubic |
| **MARCASITE** | $FeS_2$ | Orthorhombic |
| **ARSENOPYRITE** | $FeAsS$ | Orthorhombic |

GALENA-CHALCOCITE GROUPS

| | | |
|---|---|---|
| **GALENA** | $PbS$ | Cubic |
| **Argentite** | $Ag_2S$ | Cubic |
| **CHALCOCITE** | $Cu_2S$ | Orthorhombic |

| | | |
|---|---|---|
| **CINNABAR** | $HgS$ | Hexagonal |

### (*b*) Sulpho-minerals

(*a*) *General Formula,* $M'_xR'''_2S_{\frac{x}{2}+3}$

| | | |
|---|---|---|
| **CHALCOPYRITE** | $Cu_2Fe_2S_4$ | Tetragonal |
| **BORNITE** | $Cu_xFe_2S_{\frac{x}{2}+3}$ | Cubic |
| **Proustite** | $Ag_6As_2S_6$ | Hexagonal |
| **Pyrargyrite** | $Ag_6Sb_2S_6$ | Hexagonal |
| **Bournonite** | $Pb_2Cu_2Sb_2S_6$ | Orthorhombic |
| **TETRAHEDRITE** | $M_3R'''_2S_7$ | Cubic |

(*b*) *General Formula,* $M'_xR_2''S_{\frac{x}{2}+5}$

| | | |
|---|---|---|
| **Enargite** | $Cu_6AS_2S_8$ | Orthorhombic |

These minerals generally possess a metallic luster, and are opaque and heavy.

### *a.* Sulphides and Arsenides

Only the important simple sulphides and arsenides will be described.

**REALGAR, AsS.**

Monoclinic, prismatic class. Crystals are usually short prismatic. Occurs also in granular and compact masses and as incrustations and coatings.

Cleavages parallel to clinopinacoid and orthoprism. Conchoidal fracture. Hardness 1.5 to 2. Specific gravity 3.5. Resinous luster. Aurora-red to orange yellow color. Orange-yellow streak. Transparent to translucent.

AsS, sometimes written $As_2S_2$. Alters to orpiment.

Occurs with ores of silver and antimony, and is usually associated with orpiment. Frequently disseminated in clay or dolomite; also as a sublimation product and as a deposit from hot springs.

Some notable localities are: Kapnik and Felsobanya, Hungary; Joachimsthal, Bohemia; Allcahr, Macedonia; Binnenthal, Switzerland;

Mount Vesuvius; Iron County, Utah; Yellowstone Park; San Bernardino and Trinity Counties, California.

This mineral is usually found well represented by beautiful specimens in mineral collections, but is of no economic importance. The artificial compound is used in the manufacture of fire works and pigments.

**ORPIMENT** (*Auripigment, Arsenical Gold Ore*), $As_2S_3$.

Monoclinic, prismatic class. Crystals are short prismatic, but not common. Usually in foliated or granular masses, sometimes as crusts.

Cleavage parallel to clinopinacoid. Flexible but not elastic. Hardness 1.5 to 2. Specific gravity 3.5. Resinous to pearly luster. Lemon yellow color and streak. Translucent to opaque. Very much like realgar, but differs in color.

$As_2S_3$, often formed from realgar, with which it is commonly associated.

Formation and occurrence are the same as for realgar.

Excellent specimens are rather common, but the mineral is not important commercially. The artificial compound is used as a pigment, and in dyeing and tanning.

**STIBNITE** (*Antimonite, Gray Antimony*), $Sb_2S_3$.

Orthorhombic, bipyramidal class. Crystals common, prismatic and highly modified (Fig. 427), often vertically striated, bent, or twisted;

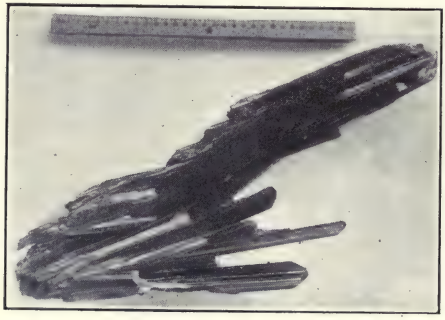


Fig. 427.—Stibnite. Province of Iyo, Island of Shikoku, Japan.

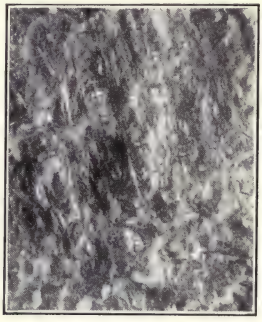


Fig. 428.—Bladed stibnite with quartz. Portugal.

also in radial aggregates; bladed (Fig. 428), columnar, granular, and compact masses.

Cleavage parallel to brachypinacoid. Slightly sectile. Metallic luster. Hardness 2. Specific gravity 4.65. Lead gray in color and streak. Often tarnishes black.

$Sb_2S_3$, sometimes contains gold and silver. Fuses easily in candle flame.

Found in veins with quartz and various antimony minerals resulting from the decomposition of stibnite. Also with galena, barite, cinnabar, sphalerite, and gold. Occurs in Saxony, Bohemia, Siberia, Algeria,

Mexico, and China. Excellent crystals have been obtained from Shikoku, Japan. The chief American localities are: Idaho, Nevada, Utah, Alaska, California; also Washington and Arkansas.

Stibnite is the chief source of metallic antimony and its compounds. It is used in fireworks, safety matches, rubber goods, and percussion caps.

Bismuthinite, $Bi_2S_3$, resembles stibnite very closely. Not common.

**MOLYBDENITE, $MoS_2$.**

Hexagonal, dihexagonal bipyramidal class. Rarely in tabular or prismatic hexagonal crystals (Fig. 429). Generally in disseminated scales or grains; sometimes in foliated or granular masses.

Excellent basal cleavage. Flexible. Greasy feel. Marks paper. Blue gray in color (graphite is black). Hardness 1 to 1.5. Specific gravity 4.75 (graphite 1.9 to 2.3). Greenish streak on glazed porcelain (graphite shiny black).

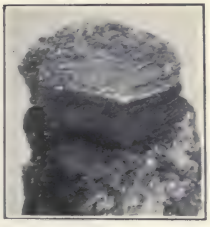


FIG. 429.—Molybdenite. Wakefield, Quebec.

$MoS_2$, sometimes contains gold or silver.

Generally disseminated in granites, especially those associated with tin ore deposits; also in syenites, gneisses, and crystalline limestones. Commonly with cassiterite, wolframite, topaz, epidote, and chalcopyrite. Large crystals occur in Renfrew County, Ontario. Important occurrences in Saxony and Bohemia; Cornwall, England; Queensland and New South Wales, Australia; Cooper and Blue Hill, Maine; Westmoreland, New Hampshire; Crown Point, Chelan County, Washington; Pitkin, Colorado.

Chief source of molybdenum and its compounds. Used in the manufacture of molybdenum "high speed" steels.

### Sphalerite-pyrrhotite Groups

These groups form an important isodimorphous series, sphalerite and related minerals crystallizing in the cubic system, while the members of the pyrrhotite group belong to the hexagonal system.

**SPHALERITE** (*Blende, Zinc Blende, Black Jack*), **ZnS.**

Cubic, hextetrahedral class. Crystals are common; often highly modified, and distorted or rounded (Fig. 433). Tetrahedrons with cube or rhombic dodecahedron are most commonly observed (Figs. 430 and 431). Twins according to the Spinel law. Generally incleavable, fine to coarse granular, and compact masses; also fibrous and botryoidal.

Highly perfect rhombic dodecahedral cleavage (Fig. 432). Brittle. Resinous to adamantine luster. Hardness 3.5 to 4. Specific gravity 3.9 to 4.2. Color varies greatly; when pure, white; commonly, yellow, red, black, or green. Transparent to translucent. Streak white, pale

yellow, or brown. Sometimes phosphoresces when broken, rubbed, or scratched (*Triboluminescence*).

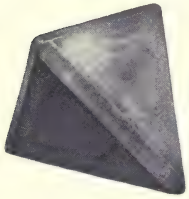


FIG. 430.

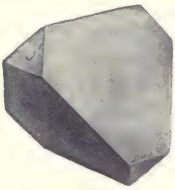


FIG. 431.

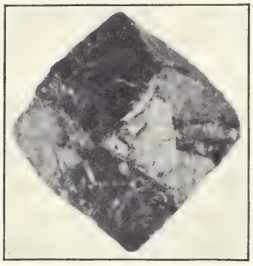


FIG. 432.—Sphalerite. Cleavage rhombic dodecahedron. Joplin, Missouri.

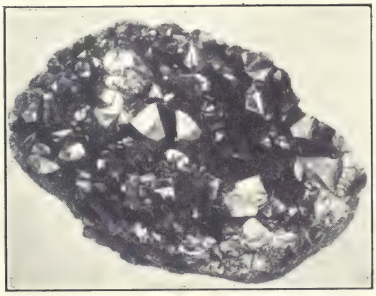


FIG. 433.—Sphalerite. Joplin, Missouri.

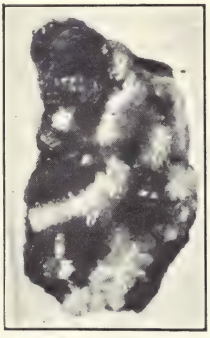


FIG. 434.—Sphalerite with quartz and galena, Kapnik, Hungary.

FIG. 435.—Sphalerite in chert. Galena, Illinois.

FIG. 436.—Sphalerite with galena and calcite. Webb City, Missouri.

ZnS, usually contains iron, up to 18 per cent., also manganese, cadmium, or mercury.

Occurs extensively in dolomitic limestones and other sedimentary rocks, as also in crystalline rocks. Usually associated with galena, chalcopyrite, pyrite, barite, fluorite, siderite, rhodochrosite, and quartz (Figs. 434, 435, and 436). Commonly in veins and cavities; also in extensive deposits. Important localities are: Freiberg, Saxony; Pribram, Bohemia; Binnenthal, Switzerland; Cornwall, England; and Yechigo, Japan.

In the United States, sphalerite is very common in the limestones of Missouri, Kansas, Oklahoma, Wisconsin, Arkansas, Iowa, and Illinois; beautiful crystals at Joplin, Missouri. Also found with lead and silver ores in the western states. Found in many places in smaller quantities.

Sphalerite is the chief source of zinc. Metallic zinc, known commercially as *spelter*, is used in large quantities in galvanizing iron and in the manufacture of brass, zinc wire and sheets, shot, dust zinc, electric batteries. The various compounds of zinc are employed extensively as pigments, in chemistry and medicine.

The following three minerals belong to the sphalerite group but are not common: Alabandite, MnS; Pentlandite (Fe, Ni)S; Troilite, FeS.

**PYRRHOTITE** (*Magnetic Pyrites*), **FeS.**

Hexagonal, ditrigonal pyramidal class. Crystals are tabular or pyramidal (Fig. 437), but not common. Usually massive, granular or lamellar.

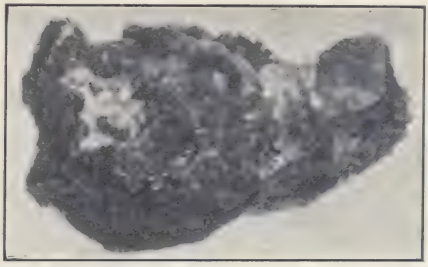


Fig. 437.—Pyrrhotite with sphalerite. Near El Paso, Texas.

Inferior basal cleavage. Brittle. Hardness 3.5 to 4. Specific gravity 4.5 to 4.6. Metallic luster. Opaque. Bronze yellow to bronze red in color, tarnishing easily to dark brown. Streak grayish black. Powder frequently attracted by the magnet.

FeS, with up to 6 per cent. of sulphur in solid solution. Often contains nickel and cobalt.

Usually as a magmatic segregation in basic igneous rocks such as gabbros, norites, and peridotites, and commonly associated with pyrite, chalcopyrite, pentlandite, and galena. Important localities are: Kongsberg, Norway; Bodenmais, Bavaria; Sudbury, Canada; Stafford and Ely,

Vermont; Ducktown, Tennessee; Gap Mine, Lancaster County, Pennsylvania.

An important source of nickel and cobalt.

**NICCOLITE** (*Copper Nickel*), **NiAs.**

Hexagonal, ditrigonal pyramidal class. Crystals are rare. Nearly always massive or disseminated (Fig. 438).

Uneven fracture. Hardness 5.5. Specific gravity 7.3 to 7.7. Metallic luster. Light copper red in color, tarnishes brown or grayish. Often coated with a green crust of annabergite, $Ni_3As_2O_8.8H_2O$. Streak brownish black.

NiAs, with small amounts of iron, cobalt, antimony, and sulphur.

FIG. 438.—Niccolite. Cobalt, Ontario.

Commonly associated with nickel, cobalt, and silver ores, thus in the Freiberg district of Saxony; Joachimsthal, Bohemia; the Cobalt district of Ontario; in smaller quantities at Franklin Furnace, New Jersey; Silver Cliff, Colorado.

A nickel ore.

Other members of the pyrrhotite group are Wurtzite, ZnS; Greenockite, CdS; Millerite, NiS; Breithauptite, NiSb.

### Pyrite-marcasite Groups

These minerals form an interesting isodimorphous series, pyrite, cobaltite, and smaltite crystallizing in the cubic system, while marcasite and arsenopyrite possess the symmetry of the orthorhombic bipyramidal class.

**PYRITE** (*Fool's Gold, Iron Pyrites*), **$FeS_2$.**

Cubic, dyakisdodecahedral class. Crystals are common, often large. The common forms are the cube, octahedron, and pyritohedron (Figs. 439 and 440); frequently distorted and highly modified. Crystal faces, especially those of the cube, often show striations conforming to the symmetry of the dyakisdodecahedral class (Fig. 442). Penetration twins of pyritohedrons with the twinning plane parallel to a face of the rhombic dodecahedron (Fig. 441), are sometimes called crystals of the "iron cross." Also massive and disseminated granular, reniform, botryoidal, stalactitic.

Uneven fracture. Hardness 6 to 6.5. Specific gravity 4.9 to 5.2. Brittle. Metallic luster. Opaque. Pale brassy to golden yellow in color, sometimes with brown or variegated tarnish colors. Greenish to brownish black streak.

$FeS_2$, with cobalt, nickel, copper, arsenic, and gold in varying amounts. Decomposes readily, especially in a moist atmosphere. Limonite and goethite are the usual decomposition products, although various sul-

phates and sulphuric acid sometimes result. Pseudomorphs of limonite after pyrite are quite common (Fig. 443).

Pyrite is the most common sulphide mineral and hence is found very widely distributed. It occurs in rocks of all ages. Its mode of occur-

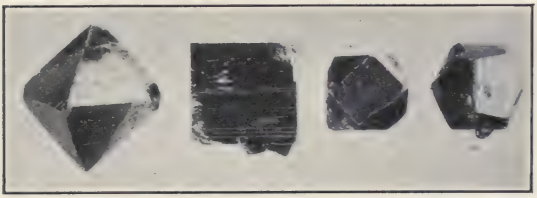


FIG. 439.—Pyrite crystals—octahedron, striated cube, cube and octahedron, pyritohedron.

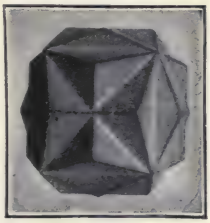


FIG. 441.

FIG. 440.—Pyrite. Bingham Canyon, Utah.

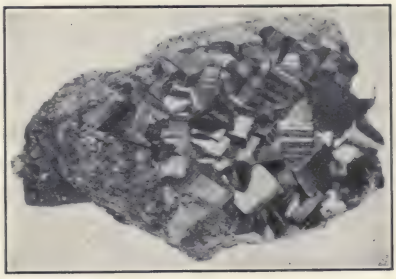


FIG. 442.—Pyrite. Striated cubes. Leadville, Colorado.

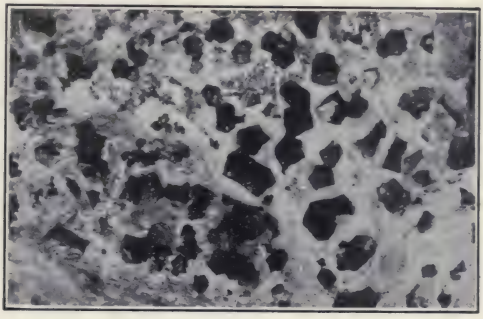


FIG. 443.—Limonite pseudomorphs after pyrite. Hartz Mountains, Germany.

rence varies greatly. Usually associated with other sulphides, such as galena, chalcopyrite, sphalerite, and arsenopyrite; also with calcite, siderite, hematite, and magnetite. Commonly found in quartz with native gold. As nodules and concretions in many slates, sandstones, and coals.

Excellent crystals are found in the Freiberg district, Saxony; Pribram, Bohemia; Schemnitz, Hungary; enormous deposits carrying gold and silver at Rio Tinto, Spain. In the United States, especially good crystals occur at Franklin Furnace, New Jersey; Central City Mine, Gilpin County, and elsewhere in Colorado; French Creek, Pennsylvania. Large deposits of massive pyrite occur in Virginia, New York, California, Massachusetts, and Georgia.

Pyrite is used principally as a source of sulphur dioxide in the manufacture of sulphuric acid, and of sulphate of iron, known as *copperas*. Pyrite is also a source of gold and copper. Small quantities are used as detectors in wireless apparatus.

**COBALTITE** (*Cobalt Glance*), **CoAsS.**

Cubic, dyakisdodecahedral class. Usually as small, well developed crystals showing either the cube or pyritohedron. Sometimes both in combination. Cube faces striated as shown in Fig. 442, page 209. More rarely compact and granular.

Cubical cleavage. Uneven fracture. Brittle. Hardness 5.5. Specific gravity 6 to 6.4. Metallic luster. Opaque. Silver white color, at times with a reddish tinge; grayish if much iron is present. Often with a pink coating of erythrite, $Co_3As_2O_8.8H_2O$. Grayish black streak.

CoAsS, usually with iron up to 12 per cent.

Generally in small quantities with other cobalt minerals; also with pyrrhotite, chalcopyrite, pyrite, galena, magnetite. Occurs at Tunaberg, Sweden; Skutterud and Nordmark, Norway; Cornwall, England; Cobalt district, Ontario.

A source of cobalt.

**SMALTITE, $CoAs_2$.**

Cubic, dyakisdodecahedral class. Crystals generally cubic in habit but rare. Usually massive,—compact, granular, lamellar, or fibrous.

Uneven fracture. Brittle. Hardness 5.5. Specific gravity 6.4 to 6.6. Metallic luster. Opaque. Tin white to light steel gray in color. Tarnishes dull. Often coated with erythrite, $Co_3As_2O_8.8H_2O$. Grayish black streak. Garlic odor when struck with a hammer. Difficult to distinguish by physical properties from chloanthite, $NiAs_2$.

$CoAs_2$, usually with varying amounts of nickel, iron, and sulphur. Iron may amount to 18 per cent., causing higher specific gravity.

Most common cobalt mineral; usually with cobalt, nickel, and silver ores; also native bismuth, barite, siderite, quartz, arsenopyrite. Thus, in the Freiberg district, Saxony; Cornwall, England; Tunaberg Sweden; La Motte mine, Missouri; Cobalt district, Ontario.

An important source of cobalt.

Other members of the pyrite group are Hauerite, $MnS_2$; Gersdorffite, NiAsS; Ullmannite, NiSbS; Chloanthite, $NiAs_2$; Sperrylite, $PtAs_2$.

**MARCASITE** (*White Iron Pyrites, Spear Pyrites*), **$FeS_2$.**

Orthorhombic, bipyramidal class. Crystals usually tabular or short columnar; elongated and striated parallel to *a* axis. Often twinned resembling cock's combs or spear heads (Figs. 444 and 445). Commonly massive fine granular, stalactitic, reniform, and globular; often with radial structures.

Hardness 6 to 6.5. Specific gravity 4.6 to 4.8. Metallic luster. Pale brass yellow to steel gray in color, darker after exposure. Usually lighter in color than pyrite. Streak greenish black.

$FeS_2$, contains at times arsenic and copper. Alters more readily than pyrite forming limonite and melanterite. Powdered marcasite dissolves in concentrated nitric acid with separation of sulphur, while pyrite does not.

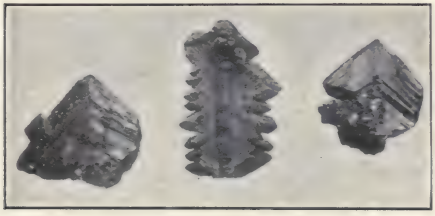


FIG. 444.—Marcasite. Ossegg, Bohemia.

FIG. 445.—Marcasite. Ossegg, Bohemia.

Not as abundant as pyrite. When massive difficult to distinguish from pyrite. Frequently with pyrite, galena, calcite, fluorite, and sphalerite. Common as concretions in marl, clay, limestone, and coal. In chalk marl at Folkestone, England; Bohemia; Saxony; with sphalerite, galena, and calcite at Joplin, Missouri; Mineral Point, Wisconsin; Galena, Illinois.

Uses same as for pyrite.

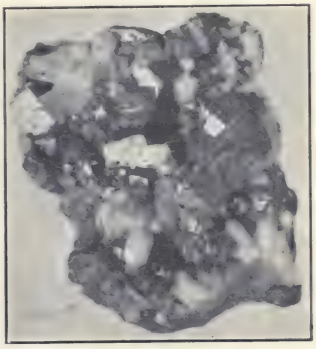


FIG. 447.—Arsenopyrite with quartz and galena. Freiberg, Germany.

**Arsenopyrite** (*Mispickel*), **FeAsS.**

Orthorhombic, bipyramidal class. Often in disseminated, tabular or short prismatic crystals (Fig. 446). Striated parallel to the *a* axis (Fig. 447). Sometimes twinned. More generally massive,—compact, granular, columnar, or radial.

FIG. 446.

Hardness 5.5. to 6. Specific gravity 5.9 to 6.2. Color silver white

to light steel gray, tarnishing brass yellow or gray. Streak black. Metallic luster.

FeAsS, often contains cobalt, antimony, bismuth, gold, and silver.

Commonly with ores of tin, nickel, cobalt, silver, gold, and lead; also with pyrite, chalcopyrite, and sphalerite. Found at Freiberg, Saxony; in serpentine at Reichenstein, Silesia; Cornwall, England; Tunaberg, Sweden; in dolomite in Binnenthal, Switzerland; in gold bearing quartz veins at Deloro, Ontario; Franconia, New Hampshire; Floyd and Montgomery counties, Virginia; Washington.

Used principally as a source of white arsenic or arsenious oxide, the arsenic of commerce. If present in paying quantities, gold, silver, and cobalt are recovered.

Other members of the marcasite group are Löllingite, $FeAs_2$; Glaucodote, $(Co,Fe)AsS$; Safflorite, $CoAs_2$; Wolfachite, $Ni(As, S, Sb)_2$; Rammelsbergite, $NiAs_2$.

## Galena-chalcocite Groups

These groups form an isodimorphous series. The members of the galena group, of which only galena and argentite will be described, crystallize in the cubic system. Chalcocite and related minerals are orthorhombic in development. Of the orthorhombic group, only chalcocite is of suffiicent importance to warrant a description.

**GALENA** (*Galenite, Lead Glance*), **PbS.**

Cubic, hexoctahedral class. Well developed crystals are common. Usual forms are the cube (*h*), and octahedron (*o*), independently or in

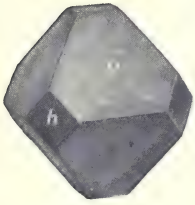



FIG. 448.

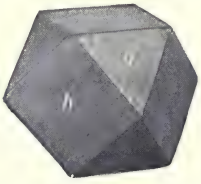



FIG. 449.

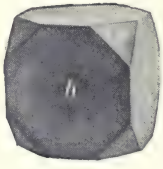



FIG. 450.

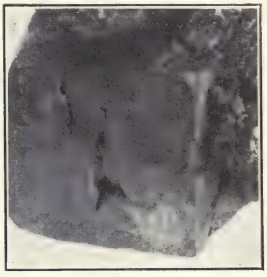


FIG. 451.—Galena. Joplin, Missouri.

combination, also the rhombic dodecahedron (*d*), (Figs. 448, 449, 450, and 451). Most generally in cleavable masses; also compact, coarse to fine granular, more rarely stalactitic or fibrous.

Perfect cubical cleavage (Fig. 452). Hardness 2.5. Specific gravity 7.3 to 7.6. Metallic luster, especially on cleavage surfaces (Fig. 453); otherwise rather dull. Lead gray color. Grayish black streak.

PbS, often with small amounts of silver. On this account galena

is an important source of silver. Galena with curved surfaces is apt to carry higher silver values than that with a good cubical cleavage. Antimony, iron, zinc, gold, or bismuth may also be present. Alters to cerussite, anglesite, and pyromorphite.

Found in veins in crystalline rocks associated with sphalerite, chalcocite, bournonite, quartz, various silver ores, calcite, and barite; often silver bearing. Thus, at Wallace, Idaho; Leadville, Colorado; Tintic and Park City Districts, Utah; Freiberg, Saxony; Pribram, Bohemia, Cumberland, England; Mexico; Chile. Also in large quantities in

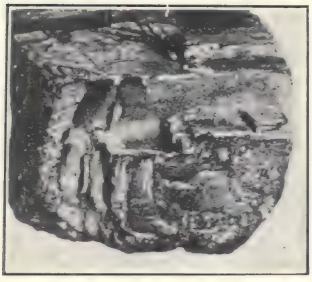


FIG. 452.—Galena showing cubical cleavage.

FIG. 453.—Galena (light). Flat River, Missouri.

Missouri, Illinois, Kansas, Wisconsin, and Iowa, in non-argentiferous veins, irregular deposits, or replacement deposits in limestones, with calcite, sphalerite, chalcopyrite, smithsonite, and marcasite. Excellent crystals occur at Joplin, Missouri, and Mineral Point, Wisconsin.

Galena is the chief source of metallic lead. It is also a valuable silver ore. Metallic lead is used extensively in the manufacture of paint, pipes and sheets, shot, solder, type metal, easily fusible alloys, and the various compounds of lead.

**Argentite** (*Silver Glance*), **$Ag_2S$.**

Cubic, hexoctahedral class. Crystals are cubic, octahedral, or rhombic dodecahedral in habit, often distorted and in parallel groups (Fig. 454). Crystals are, however, not common. Generally disseminated, coatings, or arborescent.

Hardness 2 to 2.5. Specific gravity 7.2 to 7.4. Malleable, sectile; takes an impression. On fresh surface high metallic luster, but on exposure soon becomes dull and black. Dark lead gray color. Shiny lead gray streak.

Commonly in veins associated with silver, cobalt, and nickel minerals; proustite, pyrargyrite, smaltite, niccolite, native silver. Occurs at Com-

stock Lode and Tonopah, Nevada; Aspen, Colorado; Cobalt district, Ontario; Guanajuata and Batopilas, Mexico; Freiberg, Saxony; Joachimsthal, Bohemia; Peru; and Chile.

An important ore of silver.

Fig. 454.—Argentite. Batopilas, Mexico.

Clausthalite, PbSc; Altaite, PbTe; Hessite, $Ag_2Te$, also belong to the galena group.

**CHALCOCITE** (*Copper Glance*), **$Cu_2S$.**

Orthorhombic, bipyramidal class. Crystals are tabular or thick prismatic and pseudohexagonal, the prism angle being 119° 35′ (Figs. 455 and 456). Striated parallel to the *a* axis. Frequently twinned. Crystals not common. Usually massive,—compact, granular, or disseminated.

Hardness 2.5 to 3. Specific gravity 5.5 to 5.8. High metallic luster on fresh surface, which soon becomes dull and black. Conchoidal fracture. Color dark lead gray, often tarnished blue or greenish. Shiny lead gray streak.

$Cu_2S$, usually with varying amounts of iron; also gold and silver. Alters to covellite, malachite, and azurite.

Commonly found in veins with bornite, chalcopyrite, tetrahedrite, galena, enargite, pyrite, and covellite. Found in large quantities in the

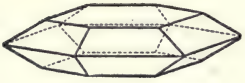


Fig. 455.

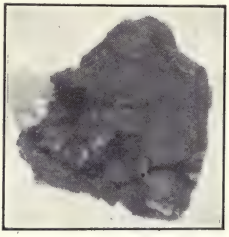


Fig. 456.—Chalcocite. Cornwall, England.

Butte district, Montana; Kennecott, Copper River district, Alaska; Nevada; Arizona; Sonora, Mexico; excellent crystals at Cornwall, England, and Bristol, Connecticut; as an impregnation at Mansfield, Germany.

Chalcocite is an important ore of copper.

Other members of the chalcocite group ore: Stromeyerite $(Cu, Ag)_2S$, and Petzite $(Ag, Au)_2Te$.

**CINNABAR** (*Natural Vermilion*), **HgS.**

Hexagonal, trigonal trapezohedral class. Extremely small, highly modified crystals; rhombohedral or thick tabular in habit. Trigonal

trapezohedral faces are rarely observed. Usually in fine grained masses, crystalline crusts, or powdery coatings.

Hardness 2 to 2.5. Specific gravity 8 to 8.2. Adamantine to dull luster. In thin plates transparent, otherwise opaque. Color varies with impurities and structure and may be scarlet, brownish red, brown, black, or lead gray. Scarlet to reddish brown streak. If moistened with HCl and rubbed on clean copper, silver white streaks are produced.

HgS, may contain bitumen, clay, ferric, oxide, etc.

Cinnabar is found in veins, disseminated, or in irregular masses in sedimentary rocks, quartzites, trachytes, porphyries, and serpentine. Usual associates are native mercury, pyrite, marcasite, realgar, calcite, stibnite, quartz, and opal. In sandstones at Almaden, Spain; in shales and dolomites at Idria, Austria; Moschellandsberg, Bavaria; excellent crystals in Kweichow, China; Chile; Peru; in serpentine at New Almaden, Altoona, and New Idria, California; also Terlinqua, Texas.

Cinnabar is the chief source of metallic mercury which is used extensively in commerce and industry.

Covellite, CuS, an indigo blue copper mineral, is closely related to cinnabar in composition and crystallization. Found with other copper minerals.

### (*b*) Sulpho-minerals

Most of the important sulpho-minerals can be referred to two general formulas:

(*a*) $M'_xR'''_2S_{\frac{x}{2}+3}$ (*b*) $M'_xR^v_2S_{\frac{x}{2}+5}$

In these formulas M′ is principally Cu, Ag, and Pb, while R‴ may be ferric iron, arsenic, and antimony. In the second formula, $R^v$ is pentavalent arsenic.

(*a*) General formula $M'_xR'''_2S_{\frac{x}{2}+3}$

Six minerals with these general compositions will be described.

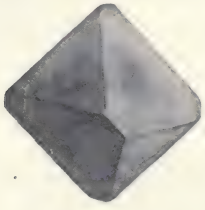


Fig. 457.

Fig. 458.

**CHALCOPYRITE** (*Copper Pyrites, Yellow Copper Ore*), $Cu_2Fe_2S_4$.

Tetragonal, bisphenoidal class. Bisphenoidal crystals resembling octahedrons, often distorted and difficult to interpret (Figs. 457, 458 and 459). Commonly in compact or disseminated masses (Fig. 460).

Uneven fracture. Hardness 3.5 to 4. Specific gravity 4.1 to 4.3. Brass to golden yellow in color. Tarnishes to various blue, purple, and blackish tints; often iridescent. Greenish black streak.

$Cu_2Fe_2S_4$, contains at times small but valuable amounts of gold and silver; also selenium, thallium, and arsenic.

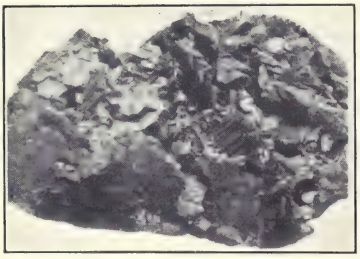


FIG. 459.—Chalcopyrite crystals. French Creek, Pennsylvania.

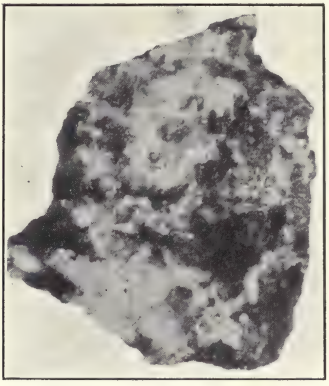


FIG. 460.—Chalcopyrite (dark) with quartz. Bruce Mine, Canada.

Most common copper mineral. Usually with pyrite, sphalerite, bornite, galena, tetrahedrite, chalcocite, malachite, azurite, quartz, and calcite. Occurs at Falun, Sweden; Rio Tinto, Spain; Cornwall, England; Sudbury district, Canada; Chile; Butte district, Montana; Bingham, Utah; Bisbee, Arizona; Ducktown, Tennessee; California; French Creek, Pennsylvania.

An important ore of copper.

**BORNITE** (*Purple Copper Ore, Horse Flesh Ore*), $\mathbf{Cu_xFe_2S_{\frac{x}{2}+3}}$.

Cubic, hexoctahedral class. Cubic and rhombic dodecahedral crystals; very rare. Commonly in compact and granular masses.

Uneven fracture. Hardness 3. Specific gravity 4.9 to 5.2. Metallic luster. Color on fresh fracture surface is between bronze and copper red, tarnishing readily and showing brilliant peacock colors. Streak gray black.

$Cu_xFe_2S_{\frac{x}{2}+3}$, where $x$ is commonly 6, 10, or 12.

Frequently contains small amounts of gold and silver.

Occurs with chalcopyrite, chalcocite, enargite, and other copper minerals; also with cassiterite, pyrite, and siderite. Not very common in Europe. Good crystals at Cornwall, England, and Bristol, Connecticut. In large quantities in the Butte district, Montana; Virginia; North Carolina; Acton, Canada; Chile; Peru; Bolivia.

An important copper ore.

**PROUSTITE** (*Light Ruby Silver Ore, Light Red Silver Ore*), $Ag_6As_2S_6$. Hexagonal, ditrigonal pyramidal class. Crystals often small, highly modified, and difficult to interpret. Hemimorphic development sometimes distinct. Generally massive,—disseminated, in crusts, or bands.

Conchoidal fracture. Hardness 2.5. Specific gravity 5.5 Brilliant adamantine to dull luster. Translucent to transparent. Color and streak scarlet to vermilion.

$Ag_6As_2S_6$, at times contains some antimony.

Occurs with pyrargyrite in veins with other silver minerals, galena, and calcite. Occurs at Freiberg, Saxony; Joachimsthal, Bohemia; Chanarcillo, Chile; Guanajuato, Mexico; Peru; Cobalt, Canada; various places in Colorado; Nevada; Idaho; Arizona.

An ore of silver.

**PYRARGYRITE** (*Dark Ruby Silver Ore, Dark Red Silver Ore*), $Ag_6$-$Sb_2S_6$.

Hexagonal, ditrigonal pyramidal class. Crystals resemble those of proustite; rare. Usually massive,—compact, disseminated, crusts, or bands.

Conchoidal fracture. Hardness 2.5 to 3. Specific gravity 5.8. Metallic adamantine luster. Dark red to lead gray in color; thin splinters in transmitted light are deep red. Cherry to purple red streak.

$Ag_6Sb_2S_6$, usually contains a little arsenic.

Occurrence similar to that of proustite but more abundant. Found in veins with other silver ores, calcite, and galena. Thus, in the Freiberg district, Saxony; Pribram, Bohemia; Guanajuato and Sonora, Mexico; Chile; Colorado; Nevada; Arizona; Cobalt, Ontario.

An important ore of silver.

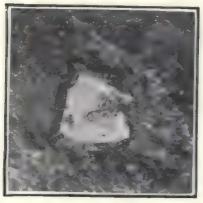


Fig. 461.—Bournonite. Pribram, Bohemia.

**BOURNONITE** (*Cog-wheel Ore*), $Pb_2Cu_2Sb_2S_6$.

Orthorhombic, bipyramidal class. Thick tabular and prismatic crystals (Fig. 461). Frequently twinned, forming *cross* or *cog-wheel* crystals (Fig. 462). Also in compact and granular masses.

Fig. 462.—Bournonite (cog-wheel ore) and sphalerite. Kapnik, Hungary.

Hardness 2.5 to 3. Specific gravity 5.7 to 5.9. On fresh fracture surface greasy. Metallic luster; crystals are sometimes dull. Steel-gray to iron black in color. Dark gray to black streak.

$Pb_2Cu_2Sb_2S_6$, usually contains some arsenic.

Occurs in veins with galena, sphalerite, stibnite, chalcopyrite, tetrahedrite, siderite, and chalcocite at Freiberg, Saxony; Pribram, Bohemia;

Kapnik, Hungary; Mexico; Chile; Bolivia; excellent large crystals at Park City, Utah; Yavapai County, Arizona; Montgomery County, Arkansas.

An ore of lead and copper.

The following minerals also belong to this group; Miargyrite, $Ag_2Sb_2S_4$; Jamesonite, $Pb_2Sb_2S_5$; Stephanite, $Ag_{10}Sb_2S_8$; Pearceite $(Ag,Cu)_{16}As_2S_{11}$; Polybasite $(Ag,Cu)_{18}Sb_2S_{12}$.

**TETRAHEDRITE** (*Gray Copper Ore*), $\mathbf{M'_8\ R'''_2S_7}$.

Cubic, hetetrahedral class. Excellent crystals showing tetrahedral development (Figs. 463, 464, and 465), often highly modified. Commonly massive,—compact, granular, disseminated.

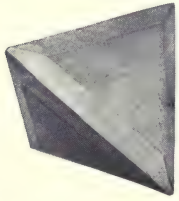


Fig. 463.

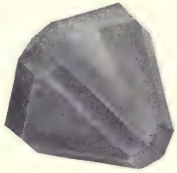


Fig. 464.

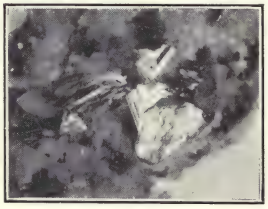


Fig. 465.—Tetrahedrite with quartz. Kapnik, Hungary.

Uneven fracture. Hardness 3 to 4. Specific gravity 4.3 to 5.4. Metallic luster, sometimes dull. Opaque. Steel gray to iron black color, often with tarnish colors. At times coated with chalcopyrite or sphalerite. Streak black, or reddish brown.

Composition varies greatly, *M'* being usually replaced to large extent by lead, copper, mercury, silver, iron, or zinc; R''' indicates antimony and arsenic, depending upon composition. The following varieties are often differentiated,—cupriferous and arsenical, *tennantite;* argentiferous, *freibergite;* mercurial, *schwatzite.*

Occurs commonly in veins with chalcopyrite, sphalerite, galena, bournonite, pyrite, quartz, siderite, and barite. Found at Freiberg, Saxony; Clausthal, Hartz Mountains; Pribram, Bohemia; Kapnik, Hungary; Mexico; Chile; Peru; Bolivia; excellent crystals at Bingham, Utah; many places in Colorado; Montana; Nevada; and Arizona.

An important ore of copper and silver.

**(b) General Formula, $\mathbf{M'_xR'''_2S_{\frac{x}{2}+5}}$**

Only one mineral with a composition conforming to the above formula is sufficiently common to warrant a description.

**ENARGITE, $\mathbf{Cu_6As_2S_8}$.**

Orthorhombic, bipyramidal class. Small prismatic, crystals, vertically striated; rare. Usually in compact, granular, or columnar masses.

Perfect prismatic cleavage. Uneven fracture. Hardness 3. Specific gravity 4.4. Submetallic luster. Grayish black to iron black in color. In artificial light resembles sphalerite. Streak black. Opaque.

$Cu_6As_2S_8$, may contain some iron, zinc, and antimony.

In veins with other copper minerals, such as chalcopyrite, bornite, chalcocite, tetrahedrite, also pyrite. Not common in Europe. More extensive in Peru; Argentina; Chile; Bolivia; Mexico; Island of Luzon, Philippines; in large quantities in the copper mines at Butte, Montana; also in San Juan Mountains, Colorado; Tintic district, Utah.

A very important ore of copper. Also a source of arsenious oxide.

## 3. OXIDES AND HYDROXIDES

Aside from water, thirteen minerals of this group will be described.

| | | |
|---|---|---|
| | 1. Oxides | |
| **WATER** | $H_2O$ | Hexagonal |
| **QUARTZ** | $SiO_2$ | Hexagonal |
| | Rutile Group | |
| **RUTILE** | $TiTiO_4$ | Tetragonal |
| **ZIRCON** | $ZrSiO_4$ | Tetragonal |
| **CASSITERITE** | $TiTiO_4$ | Tetragonal |
| **Pyrolusite** | $MnO_2$ | |
| **Zincite** | $ZnO$ | Hexagonal |
| | Hematite Group | |
| **CORUNDUM** | $Al_2O_3$ | Hexagonal |
| **HEMATITE** | $Fe_2O_3$ | Hexagonal |
| **CUPRITE** | $Cu_2O$ | Cubic |
| | 2. Hydroxides | |
| **OPAL** | $SiO_2xH_2O$ | Amorphous |
| **MANGANITE** | $MnO.OH$ | Orthorhombic |
| **BAUXITE** | $Al_2O.(OH)_4$ | |
| **LIMONITE** | $Fe_2O_3.H_2O$ | Amorphous |

### (*a*) Oxides

Many of these minerals are very common and of great economic importance.

**WATER,** *Snow, Ice,* **$H_2O$.**

Above 0°C. water is a liquid, hence, amorphous. It is almost colorless, but in large quantities and when pure, it has a bluish tinge. Specific

gravity, when pure, at 4°C. and 760 mm. barometric pressure is 1; that of ocean water may be as high as 1.028. When pure it is without taste or odor.

Water occurs very widely distributed in nature and is an important agency in the disintegration, decomposition, transportation, and formation of minerals. Nearly all minerals are more or less soluble in water, especially if it contains carbon dioxide, humus acid, hydrochloric acid, or oxygen in solution. The ocean water contains about 3.4 per cent. of solid matter in solution. Over thirty elements are found in ocean water and, hence, water is frequently called the universal solvent. When water freezes it expands, the increase in volume being about 9 to 10% and the pressure exerted about 138 tons per square foot. Due to this enormous pressure, freezing water is a most important geological agency, causing the widening of cracks and crevices thereby extending the zone of activity of water and oxygen and hastening weathering and decomposition.

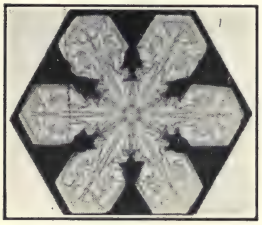


FIG. 466.—Snow crystal. (*After Bentley*).

On freezing, water forms snow or ice. Snow crystals are often very beautiful. They are tabular and hexagonal in outline (Fig. 466), and show great diversity in development. Lake or stream ice consists of crystals arranged in a definite manner, the *c* axes being perpendicular to the extent of the sheet of ice. In glacier ice, however, the ice particles do not possess a definite orientation.

**QUARTZ, $SiO_2$.**

Hexagonal, trigonal trapezohedral class (below 575°C.). Crystals are very common. They usually consist of an hexagonal prism, which

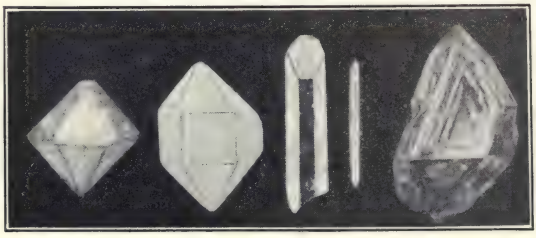


FIG. 467.—Quartz crystals—pyramidal, prismatic, long prismatic, tabular, skeletal.

predominates, terminated by faces of a positive and negative rhombohedron so developed as to simulate the hexagonal bipyramid of the first order. The pyramidal habit is less frequent. The prism faces are generally horizontally striated (Fig. 467). Crystals are sometimes bent, twisted, or greatly distorted. Quartz forms right- and left-handed crystals, which are easily recognized when faces of the trigonal trapezo-

hedron are present (Fig. 468 left, Fig. 469 right). Twins are common. Figure 470 illustrates the common or Dauphine law, the vertical axis being the twinning axis. Here two right- or left-hand crystals interpenetrate so that the positive rhombohedron of the one individual coincides with the negative of the other, the *c* axis being the twinning axis.

Crystals twinned according to the Brazilian law (Fig. 471) consist of a right- and a left-hand individual of the same sign so interpenetrated

FIG. 468.

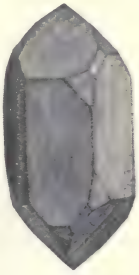


FIG. 469.

FIG. 470.

FIG. 471.

that the twinned crystals are symmetrical to planes parallel to faces of the prism of the second order. Twins according to several other laws are not uncommon. Crystals sometimes show a skeletal development (Fig. 472).

At times crystals contain scales of mica or hematite distributed in a regular manner, so that they may be separated into sections or layers.

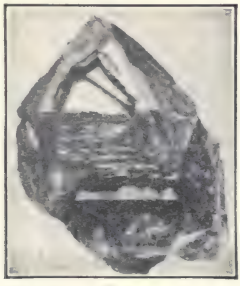


FIG. 472.—Skeletal quartz. Paris, Maine.

FIG. 473.—Scepter quartz with phantom. Mursink, Ural Mountains.

Such crystals are called *cap quartz*. Parallel growths called *scepter quartz* (Fig. 473) are also observed. Although quartz is commonly found in distinct crystals, it also occurs in a great variety of massive forms.

Conchoidal fracture. Hardness 7. Specific gravity 2.65. Vitreous luster. Transparent to opaque. Commonly colorless or white, also yellow, red, pink, amethystine, green, blue, brown, and black. Many colors disappear on heating. Streak white.

$SiO_2$. Often contains inclusions of rutile, hematite, chlorite, mica, and liquid and gaseous carbon dioxide. Not attacked by the common acids, and infusible before the blowpipe. Common as a pseudomorph after fluorite, calcite, siderite, and wood.

The many varieties of quartz are most conveniently classified as, (*a*) *crystalline*, (*b*) *cryptocrystalline*, and (*c*) *clastic*.

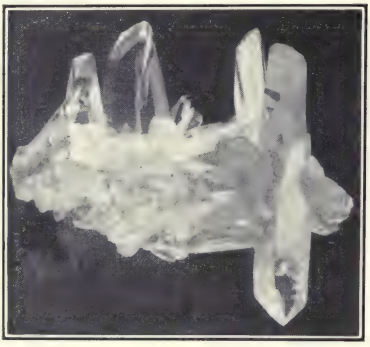


FIG. 474.—Quartz, Dauphine, France.

FIG. 475.—Smoky quartz with muscovite. Paris, Maine.

(a) **Crystalline varieties** are vitreous, either crystals or crystalline masses, and but slightly acted upon by potassium hydroxide.

1. *Rock Crystal.*—Colorless quartz. Excellent crystals are common (Fig. 474).

2. *Amethyst.*—Various shades of purple or violet.

3. *Rose Quartz.*—Pink to rose red in color, becoming paler on exposure to light. Usually massive.

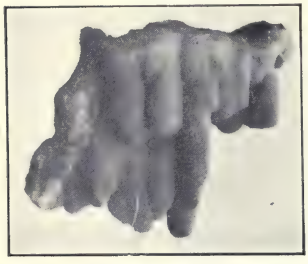


FIG. 476.—Chalcedony (stalactitic). Havana, Cuba.

4. *Smoky Quartz.*—Smoky yellow to dark brown. Often called *cairngorm stone* (Fig. 475).

5. *Milky Quartz.*—Milk-white in color. Translucent or nearly opaque. Often with a greasy luster.

6. *Yellow Quartz.*—Light yellow in color, often called *false topaz*, *Spanish topaz*, or *citrine*.

7. *Aventurine.*—Contains glistening scales of mica or hematite.

8. *Ferruginous Quartz.*—Brown or red in color, due to the presence of either limonite or hematite.

9. *Rutilated Quartz.*—Contains fine interlacing needles of rutile.

10. *Cat's Eye.*—Grayish or brownish, with an opalescence due to inclusions of fibers or to a fibrous structure.

11. *Tiger's Eye.*—Yellow brownish in color. Pseudomorphous after crocidolite. Pronounced chatoyant luster.

(b) **Cryptocrystalline varieties** are compact and under the microscope show a crystalline structure. More readily acted upon by potassium hydroxide than the crystalline varieties.

1. *Chalcedony.*—A transparent to translucent variety having a waxy luster. Commonly stalactitic (Fig. 476), botryoidal, concentionary, and lining cavities. White, grayish, brown, blue, and black in color.

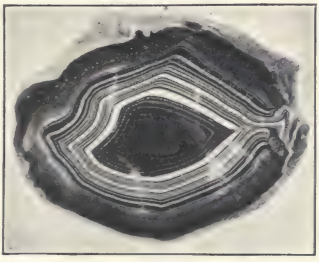


FIG. 477.—Agate. South America.

FIG. 478.—Agate. Brazil.

2. *Carnelian or Sard.*—Commonly reddish chalcedony.

3. *Chrysoprase.*—Apple-green chalcedony.

4. *Heliotrope.*—Bright or dark green chalcedony with small spots of red jasper resembling drops of blood. It is often called *bloodstone.*

5. *Agate.*—This is chalcedony made up of strata or bands indicating various stages of deposition. The layers may be differently colored or

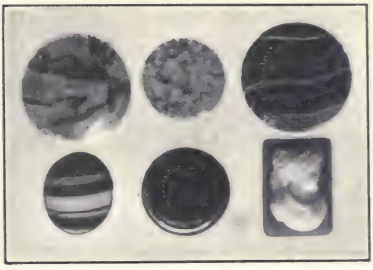


FIG. 479.—Agates—moss, banded, cameo.

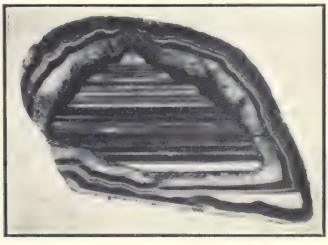


FIG. 480.—Agate with onyx in center.

clouded, giving rise to several varieties, such as *banded, moss,* and *clouded* agates.

The banding is usually in parallel, but more or less wavy or irregular lines (Figs. 477, 478, and 479). Agates may be white, pale to dark brown, or bluish in color. They are frequently colored artificially.

6. *Onyx.*—Banded agate with the bands or layers in parallel straight lines, corresponding to layers in even planes (Fig. 480).

7. *Jasper.*—Opaque, and red, yellow, and grayish in color.

8. *Flint.*—Gray, smoky brown, or brownish black in color. Commonly in nodules with a white coating (Fig. 481). Translucent. Prominent conchoidal fracture.

9. *Chert.*—Includes varieties with a horn-like appearance, also impure flints and jaspers.

(c) **Clastic varieties** of quartz include many of the silicious fragmental rocks. In some cases the individual particles are no longer distinct.

1. *Sand.*—Loose, unconsolidated grains or fragments of quartz.

2. *Sandstone.*—Consolidated sand. The cementing material may be silica, iron oxide, calcium carbonate, or clay. Occurs in a great variety of colors.

3. *Itacolumite.*—A flexible sandstone. Contains some mica.

4. *Quartzite* or *Granular Quartz.*—Metamorphosed sandstone in which the cement is silica. The individual quartz particles are generally not easily recognized by the naked eye.

FIG. 481.—Flint. Dover Cliffs, England.

Next to water, quartz is the most common of all oxides. It is a very important rock-forming mineral, being a primary constituent of many igneous and sedimentary rocks, and occurs in rocks of all ages and in many ore deposits. It is also found very abundantly as sand and gravel.

Rock crystal, amethyst, smoky and rose quartz, aventurine, cat's eye, tiger's eye, chalcedony, agate, and jasper are used rather extensively in jewelery and for ornamental purposes; agate and chalcedony for mortars and pestles; rock crystal for dishes, vases, optical instruments, spectacles, and chemical apparatus; sand for mortar, plaster, glass, and sandpaper; sandstone and quartzite for building and paving purposes, and grindstones; and ground or crushed quartz and flint in wood fillers, pottery, scouring and polishing soaps, and as an abrasive. Large quantities of quartz are also used as a flux in metallurgical processes.

## Rutile Group

This group contains the three common oxides of titanium, tin, and zirconium and silicon, which crystallize in the tetragonal system.

**RUTILE, $TiTiO_4$.**

Tetragonal, ditetragonal bipyramidal class. Crystals are common. Usually prismatic or thick columnar, consisting of the prisms and bipyramids of the first and second orders (Fig. 482). Prism faces frequently striated vertically (Fig. 483*a*). Knee-shaped twins often observed, the twinning plane being parallel to a face of the bipyramid of the second

order (Fig. 483*b*). Also trillings, sixlings, and eightlings (rosettes) according to this law (Fig. 483*c*). Also in compact, granular masses. Needle-like crystals of rutile occur frequently as inclusions in quartz.

Distinct prismatic and pyramidal cleavages. Hardness 6 to 6.5. Specific gravity 4.2 to 4.3. Metallic adamantine luster. Opaque to transparent. Red brown, blood red, and black in color. Streak yellow or pale brown.

$TiTiO_4$, sometimes written $TiO_2$. Usually contains considerable iron. Occurs pseudomorphous after hematite, brookite, and anatase.

Rutile is the most common titanium mineral and occurs in gneiss, mica schists, granite, granular limestone, and dolomite. Commonly associated with quartz, hematite, and feldspar. Found at Arendal and Kragero, Norway; Ural Mountains; Binnenthal and St. Gothard dis-

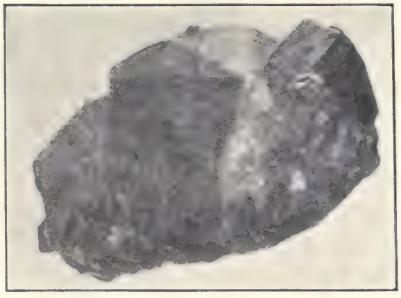


FIG. 482.—Rutile. Georgia.

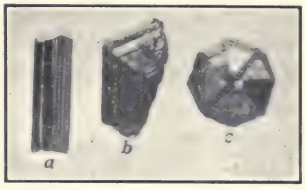



FIG. 483.—Rutile crystals—(*a*) prismatic and striated, (*b*) knee-shaped, (*c*) rosette (Eightling).

trict, Switzerland; Nelson County, Virginia; Graves Mountain, Georgia; Magnet Cove, Arkansas. Occurs also in secondary deposits with quartz, tourmaline, gold, and diamond.

Used in coloring porcelain yellow and artificial teeth bluish (pinkish) white; also in special grades of steel and copper-bearing alloys; as a mordant in dyeing leather, and in carbons for arc lights.

**ZIRCON,** *Hyacinth, Jargon,* **$ZrSiO_4$.**

Tetragonal, ditetragonal dipyramidal class. Usually in simple, well-developed crystals, consisting of the prism and bipyramid of the first order (Fig. 484); more complex crystals sometimes observed (Fig. 485). Also as rounded or angular lumps or grains in sands and gravels.

Hardness 7.5. Specific gravity 4.4 to 4.8. Adamantine luster. Transparent to opaque. Commonly brown or grayish, also red, yellow, and colorless. Transparent. Reddish and brownish varieties are often called *hyacinth* or *jacinth;* when colorless and smoky, *jargon.* Cut stones possess good brilliancy and fire.

$ZrSiO_4$. Often interpreted as a silicate. Usually contains a small amount of iron.

Occurs disseminated in the more acid igneous rocks, especially granites and syenites; also found in gneiss, schists, and crystalline limestone. Occurs in nephelite-syenite in southeastern Norway; Miask, Ural Mountains (Fig. 486); Wichita Mountains, Oklahoma; Litchfield, Maine.

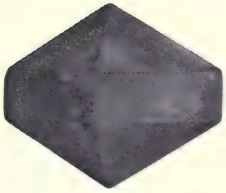


FIG. 484.

FIG. 485.

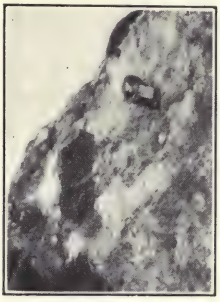


FIG. 486.—Zircon in syenite. Ilmensk, Ural Mountains.

Common in the sands and gravels of Ceylon, also in Henderson, Irdell, and Buncombe counties of North Carolina.

Zircon is a source of $ZrO_2$, which is used in limited amounts in Nernst lamp glowers. *Hyacinth, jacinth,* and *jargon* are cut as gems. The colorless zircon from Matura, Ceylon, is often called *matura diamond.*

**CASSITERITE** (*Tin Stone*), **$SnSnO_4$.**

Tetragonal, ditetragonal bipyramidal class. Crystals are usually short prismatic, showing the prisms and bipyramids of the first and second orders, similar to those of zircon. Knee-shaped twins are common, the bipyramid of the second order being the twinning plane. Frequently in disseminated, granular, or reniform masses; also in grains and pebbles. Concentric and fibrous radial structure is frequently observed.

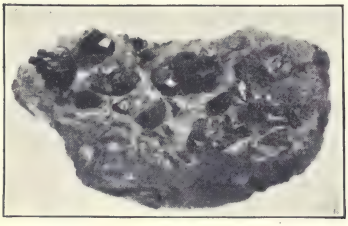


FIG. 487.—Cassiterite with fluorite. Saxony.

Hardness 6 to 7. Specific gravity 6.8 to 7. Adamantine to submetallic luster. Reddish brown, brown, black; also yellow or white. Streak white to pale brown.

Three varieties may be distinguished:

1. *Ordinary Cassiterite or Tin Stone.*—Crystals and compact masses.

2. *Wood Tin.*—Botryoidal and reniform masses of varying colors, with concentric structure and commonly with a radial fibrous structure.

3. *Stream Tin.*—Angular and rounded grains or pebbles in sands and gravels of streams.

$SnSnO_4$, sometimes written $SnO_2$. Generally contains some iron. Infusible and insoluble in acids.

Cassiterite is commonly associated with quartz, topaz, fluorite (Fig. 487), apatite, and tourmaline. It occurs generally in veins cutting granites and rhyolites, which have generally been greatly altered as the result of pneumatolytic action. Granitic rocks altered in this way are called *greisen*, while non-granitic rocks are termed *zwitter*. On account of its great resistance to weathering, cassiterite is also found extensively in secondary deposits. The Malay Peninsula of Malacca, (the Straits Settlements), the islands of Banca and Billiton near Borneo, and Bolivia are the chief producers of cassiterite. Other localites are: Cornwall, England; Altenberg, Saxony; Buck Creek, Alaska; Black Hills, South Dakota; Gaffney, South Carolina; Kings Mountain, North Carolina; El Paso, Texas.

Cassiterite is the only source of tin of commerce and industry, which is used extensively in the manufacture of tin plate or sheet tin (sheet iron or steel dipped in molten tin), solder, bronze, tin amalgam, gun metal, type metal, speculum metal, Britannia metals, and pewter. Sodium stannate is used in calico printing and the artificial oxide is used as a polishing powder.

---

**PYROLUSITE** (*Black Oxide of Manganese*), $MnO_2$.

Prismatic and needle-like crystals pseudomorphous after manganite; generally compact, fibrous, columnar, stalacitic, dendritic, or powdery crusts (Fig. 488).

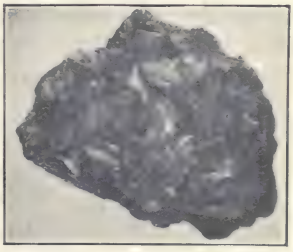


FIG. 488.—Pyrolusite. Ilfeld, Thuringia, Germany.

Hardness 1 to 2.5, soils the fingers. Specific gravity 4.8. Black or dark steel gray in color. Black or bluish black streak. Metallic to dull luster. Opaque.

$MnO_2$. Usually contains small amounts of water and silica.

Pyrolusite is a secondary mineral resulting from the decomposition of manganite, rhodochrosite, and various manganiferous iron ores. Usually found with manganite, psilomelane, hematite, or limonite.

Occurs extensively in Thuringia and in the Harz Mountains, Germany; Bohemia; France; Brazil; Russia; Hungary; Cuba. The principal localities in the United States are the Crimora district, Augusta County, Virginia; Cave Spring and Cartersville, Georgia; Batesville, Arkansas; Livermore, Alameda County, California; Brandon, Vermont.

Pyrolusite is used in the manufacture of chlorine, bromine, oxygen, ferromanganese, manganese bronze, and spiegeleisen; as a coloring agent in calico-printing and dyeing, glass, pottery, bricks, and paints; also as a

decolorizer of green glass, and in dry batteries. Spiegeleisen is of great importance in the metallurgy of iron and steel.

**ZINCITE** (*Red Zinc Ore*), **ZnO.**

Hexagonal, dihexagonal pyramidal class. Crystals are hemimorphic and consist of prisms, upper pyramid, and lower basal pinacoid. Natural crystals are very rare. Usually as compact, granular, or foliated masses (Fig. 489).

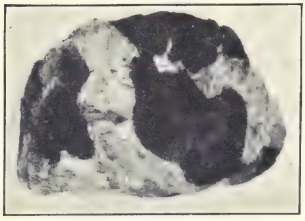


FIG. 489.—Zincite (dark) with calcite. Franklin Furnace, New Jersey.

Perfect basal cleavage. Hardness 4 to 4.5. Specific gravity 5.4 to 5.7 Subadamantine to vitreous luster. Dark red to orange or yellow in color. Reddish to orange yellow streak. Translucent to opaque.

ZnO. Usually contains some manganese and iron.

Occurs extensively at Franklin Furnace, Sussex County, New Jersey, in metamorphic limestones associated with franklinite, rhodonite, willemite, sphalerite, rhodochrosite, and calcite. Also in Schneeberg, Saxony; Tuscany; Poland.

An important ore of zinc. It has been used for detectors in wireless apparatus.

## Hematite Group

This group includes the two very important economic minerals corundum and hematite. These are the sesquioxides of aluminum and iron, respectively. They crystallize in the hexagonal system.

**CORUNDUM,** *Sapphire, Ruby, Emery,* **$Al_2O_3$.**

Hexagonal, ditrigonal scalenohedral class. Well developed crystals are common, and often rather large. The habit may be pyramidal, rhombohedral, prismatic, or tabular (Fig. 490). The most common forms are the prism of the second order, unit rhombohedron, bipyramid of the second order, and the basal pinacoid. Large crystals are sometimes rough or rounded, barrel-shaped, and deeply furrowed or striated. Penetration and polysynthetic twins are common, the twinning being parallel to the unit rhombohedron. The basal pinacoid often shows triangular striations. Occurs also in compact, granular, and lamellar masses, showing frequently a nearly rectangular parting or pseudo-cleavage.

FIG. 490.—Corundum crystals —tabular, prismatic, pyramidal, long prismatic.

Basal, and nearly rectangular rhombohedral partings. Conchoidal fracture. Hardness 9. Specific gravity 3.9 to 4.1. Commonly gray, brown, and bluish; also red, blue, yellow, and colorless. Sometimes multicolored. Transparent to translucent. Vitreous luster.

$Al_2O_3$. Crystals are usually quite pure. Small amounts of ferric oxide may be present as a pigment. Emery is generally quite impure.

Several varieties of corundum may be distinguished.

(1) *Ruby.*—This is the transparent deep red variety. It is highly prized as a gem.

(2) *Sapphire.*—The sapphire proper is a transparent blue corundum. Transparent stones of other colors are called *yellow, golden,* or *white sapphires,* etc. Sometimes the following terms are also used, when green, *oriental emerald;* yellow, *oriental topaz;* violet, *oriental amethyst.* Sapphires are also used for gem purposes.

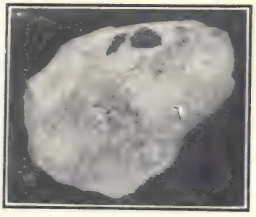


FIG. 491.—Corundum: Variety, ruby. India.

(3) *Common Corundum.*—This includes crystals and compact masses with dull and irregularly distributed colors.

(4) *Emery.*—This is an intimate mixture of corundum, magnetite, hematite, quartz, and spinel. Dark gray to black in color, and was first considered an iron ore. The admixture may be as high as 40 per cent. The hardness may be considerably lower than that of the other varieties, namely 7 to 9.

Corundum occurs usually disseminated in crystalline limestone and dolomite (Fig. 491), gneiss, mica schist, chlorite schist, nepheline syenite, granite, and other crystalline rocks. It is commonly associated with magnetite, mica, chlorite, nephelite, serpentine, and spinel.

The gem varieties are found principally in placer deposits in Ceylon, Burma, Hindustan, Siam, China, Queensland, Ural Mountains, and near Helena, Montana. Rubies and sapphires have been highly prized as gems. Latterly they have been produced synthetically in large quantities. Many of these synthetic, or reconstructed sapphires, as they are erroneously called, possess superior colors, and when small are often extremely difficult to distinguish from the natural stones.

Common corundum is found in extensive deposits associated with peridotite in North and South Carolina, and Georgia; at Raglan and elsewhere in Renfrew County, Ontario, in nepheline syenite; also in Westchester County, New York; Chester County, Pennsylvania; and Chester Massachusetts.

Most of the world's supply of emery is obtained from the islands of Naxos and Samos in the Grecian archipelago, and from Asia Minor. On Naxos and Samos it occurs in crystalline limestones and schists. It is also found in the Ural Mountains; Saxony; associated with chlorite and

margarite in amphibolite schist at Chester, Massachusetts; in peridotite at Peekskill, New York.

Ruby and sapphire are used extensively for gem purposes and as jewels in watches and various scientific instruments. Common corundum and emery are important abrasive materials.

**HEMATITE,** *Specularite, Specular Iron Ore, Red Iron Ore,* $Fe_2O_3$.

Hexagonal, ditrigonal scalenohedral class. Crystals are either thin or thick tabular, pyramidal, rhombohedral, or more rarely prismatic in

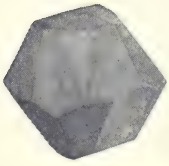


FIG. 492.

FIG. 493.—Hematite. Island of Elba.

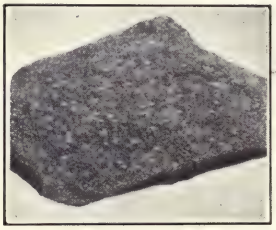


FIG. 494.—Specular hematite. Lake Superior District.

habit (Figs. 492 and 493). Tabular crystals are often arranged in rosettes and are then called *iron roses.* The basal pinacoid is frequently striated, due to polysynthetic twinning. Occurs more abundantly in compact,

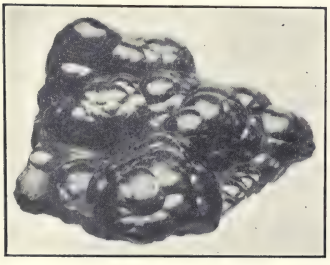


FIG. 495.—Hematite (kidney ore). Cumberland, England.

FIG. 496.—Micaceous hematite Lake Superior District.

granular (Fig. 494), columnar, fibrous, botryoidal (Fig. 495), reniform, stalactitic, micaceous (Fig. 496), oölitic, and earthy masses.

No cleavage, but a rhombohedral parting which is nearly cubical

is sometimes observed. Conchoidal to uneven fracture. Hardness 5.5 to 6.5; earthy varieties are very soft. Specific gravity 4.9 to 5.3. Metallic, splendent, or dull luster. Opaque, except in very thin scales. Commonly steel gray, reddish brown, or iron black in color; sometimes with beautiful tarnish colors. Earthy varieties are red in color. Cherry red or reddish brown streak. Sometimes slightly magnetic, due to the presence of small amount of magnetite.

$Fe_2O_3$. May contain as much as 7 per cent. of titanium dioxide; also ferrous oxide, magnesium oxide, phosphoric acid, silica, and clay. Infusible. Becomes magnetic when heated on charcoal. When powdered it is slowly soluble in acids. Occurs as a pseudomorph after calcite, siderite, pyrite, and magnetite.

There are several varieties of hematite.

(1) *Specularite or Specular Iron Ore.*—This includes crystals, micaceous, and granular masses with a metallic or splendent luster (Figs. 494 and 496). Usually steel gray or iron black in color.

(2) *Compact or Red Hematite.*—Compact masses, often with a radial fibrous structure. Submetallic to dull luster. Iron black or brownish red in color.

(3) *Kidney Ore.*—Reniform masses, usually with smooth shiny surfaces (Fig. 495).

(4) *Red Ocher.*—This includes earthy varieties, which are very soft and have a dull luster. Often contains considerable clay or sand.

(5) *Argillaceous Hematite.*—Hard and compact varieties, which are generally quite impure due to admixtures of much clay, sand, or jasper. Brownish black, reddish brown, or red in color.

(6) *Oölitic or Fossil Iron Ore.*—This variety possesses an oölitic structure, and frequently contains fossil remains.

(7) *Martite.*—Hematite occurring in octahedrons, pseudomorphous after magnetite.

Hematite is the most important iron ore. It occurs (1) in independent deposits, sometimes of great thickness and extent. (2) As an accessory mineral in many igneous rocks, such as granite and syenite. (3) In cracks and crevices, usually with quartz. (4) As an inclusion in many minerals; thus, in feldspar, quartz, and carnallite. (5) As a sublimation product in lavas; thus, on Vesuvius and Aetna. (6) Sometimes it is the result of contact metamorphism.

Excellent crystals are found on the island of Elba, in the Mediterranean Sea; St. Gothard district, Switzerland (iron roses); Arendal, Norway; Langban and Nordmark, Sweden; Cumberland, England.

Enormous deposits of hematite occur in the rocks, chiefly of Huronian and Archean ages, in the Lake Superior region of Northern Michigan, Minnesota, Wisconsin, and Canada. There are six well defined iron ranges or districts in this region, viz; *Marquette* in Michigan; *Menominee*

and *Gogebic* in Michigan and Wisconsin; *Mesabi* and *Vermilion* in Minnesota; *Michipicoten* in Ontario, Canada. In 1919 this region produced 63,735,088 long tons of iron ore, of which the greater part was mined by steam shovels operating in huge open pits. This ore includes both the hard and soft varieties. Oölitic or fossiliferous hematite occurs at Clinton, New York; and in large quantities in eastern Tennessee and Northern Alabama. Birmingham, Alabama, is the center of this important district. Important deposits of hematite also occur in Missouri, Wyoming, and Pennsylvania.

Hematite is the chief source of the iron of commerce and industry. Over 90 per cent. of the iron ore mined annually is hematite.

---

**CUPRITE** (*Ruby Copper Ore*), $Cu_2O$.

Cubic, pentagonal icositetrahedral class. Crystals are common, consisting usually of the cube (Fig. 497), octahedron, and rhombic dodecahedron, often in combination. Also compact, granular, and earthy massive; fine slender aggregates are called *chalcotrichite* or *plush copper*.

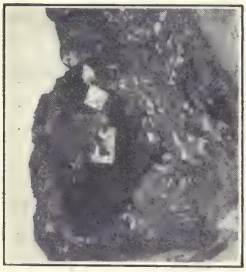


Fig. 497.—Cuprite (cubes). Bisbee, Arizona.

Hardness 3.5 to 4. Specific gravity 5.7 to 6.1. Metallic adamantine to dull luster. Ruby red to almost black in color. Transparent to opaque. Brownish red to dirty brown streak.

$Cu_2O$. Usually quite pure. Alters readily to malachite, azurite, tenorite, and native copper. Pseudomorphs of malachite after cuprite are quite common.

Cuprite is a secondary mineral, resulting from the oxidation of various copper minerals. Commonly found with malachite, azurite, native copper, chrysocolla, limonite, and chalcopyrite.

At Chessy, France, it occurs in crystals partially or completely altered to malachite; also found at Cornwall, England; Dobschau, Hungary; Chile; Peru; Bolivia; Ural Mountains. Abundant with other copper ores at Bisbee, Clifton, and Morenci, Arizona; with native copper in the Lake Superior Copper district.

An important ore of copper.

### (*b*) Hydroxides

Only the four most important hydroxides will be described. These minerals are generally of secondary origin.

**OPAL**, $SiO_2.xH_2O$.

Amorphous. Usually compact, in veins or irregular masses sometimes with botryoidal, reniform, stalactitic, or earthy structure.

Conchoidal fracture. Hardness 5.5 to 6.5; in earthy varieties may be as low as 1. Specific gravity 2.1 to 2.3. Vitreous, dull, or greasy luster. Transparent to opaque. Streak white. Color varies greatly; colorless, white, yellow, brown, red, green, gray, blue, and so forth. Often beautiful play of colors may be observed. This is due to fine cracks filled with material possessing a slightly different index of refraction than the original substance, and perhaps also to an unequal distribution of the water content. Some opaque opals show an opalescence, especially after immersion in $H_2O$.

$SiO_2.xH_2O$. The amount of water present may vary from 1 to 21 per cent., but is usually between 3 and 13 per cent. Many opals are to be considered as dried and hardened gelatinous silica. Yields water when heated in a closed tube. Infusible. Soluble in hot caustic potash or soda.

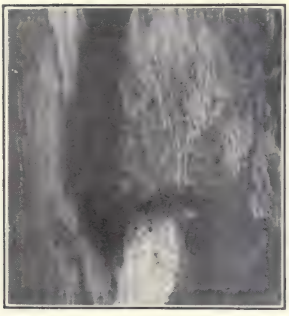


FIG. 498.—Wood opal. Storlein, Hungary.

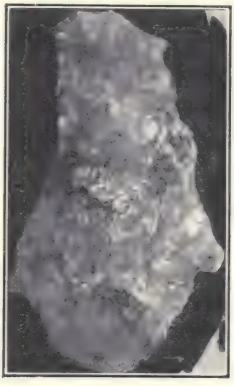


FIG. 499.—Opal: Variety, hyalite. Waltsch, Bohemia.

FIG. 500.—Opal: Variety, geyserite. Yellowstone Park.

The principal varieties of opal include:

(1) *Precious Opal.*—Yellowish white, dark gray, or bluish in color with an excellent play of colors. Those with the lighter colors are called *white opals*, while the dark gray and blue opals are designated as *black opals*.

(2) *Fire Opal.*—Orange yellow to red in color. Semi-transparent.

(3) *Common Opal.*—Translucent to opaque and shows many colors. When milk-white, yellowish, bluish, or greenish it is called *milk opal*. With a resinous luster and either wax, honey, or other yellow in color, it is *resin opal*. Wood petrified by opaline material is called *wood opal* (Fig. 498). *Opal jasper* is red, reddish brown, or yellow brown in color with a resinous luster, and resembles jasper.

(4) *Hyalite.*—Colorless and transparent masses of irregular outline. Looks like drops of melted glass (Fig. 499).

(5) *Silicious Sinter, Geyserite.*—These are opaline deposits from hot springs and geysers. May be porous, compact, fibrous, stalactitic, or botryoidal (Fig. 500); grayish, whitish, or brownish in color, and sometimes possess a pearly luster.

(6) *Tripolite, Diatomaceous or Infusorial Earth.*—Porous, earthy, and chalk-like deposits of the silicious remains of diatoms, radiolaria, and so forth. Light in weight.

Opal is commonly the result of the decomposition of silicate rocks, and is hence frequently found in cracks and cavities in igneous and sedimentary rocks. *Common Opal* occurs rather widely distributed. *Precious opal* is found at Czerwenitza, Hungary; Queretaro, and elsewhere in Mexico; Humboldt County, Nevada; Latah County, Idaho; Honduras; New South Wales, especially at White Cliffs.

*Silicious sinter or geyserite* occurs abundantly in the Yellowstone Park, Iceland, and New Zealand. *Infusorial* earth is found in considerable deposits at Richmond, Virginia; Drakesville, New Jersey; Socorro, New Mexico.

Precious and fire opals are used for gem purposes; wood opal for ornamental purposes. Infusorial earth and tripolite are used in polishing powders, scouring soaps, artificial fertilizers, paint, wood fillers, in the filtering and refining of sugar, and as non-conductor of heat.

**MANGANITE, MnO(OH).**

Orthorhombic, bipyramidal class. Commonly in deeply striated prismatic crystals, arranged in groups or bundles (Fig. 501). Also in radial fibrous and columnar masses, more rarely granular and stalactitic.

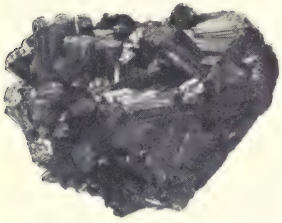


Fig. 501.—Manganite. Ilmenau, Thuringia, Germany.

Perfect brachypinacoidal cleavage. Uneven fracture. Hardness 3.5 to 4. Specific gravity 4.3. When fresh, manganite possesses a submetallic luster, an iron black color, and a reddish brown to brownish black streak. If more or less decomposed, it is steel gray in color with a black streak, and metallic luster.

MnO.OH. Soluble in concentrated hydrochloric acid with an evolution of chlorine. Occurs as a pseudomorph after calcite. Alters easily to pyrolusite.

Commonly associated with hematite, barite, calcite, siderite, pyrolusite, and other manganese minerals. Excellent crystals occur at Ilfeld, Hartz Mountains; Ilmenau, Thuringia; Langban, Sweden; Marquette County, Michigan; Douglas County, Colorado; Nova Scotia; New Brunswick; Cornwall, England.

With pyrolusite it is used extensively in the preparation of oxygen and chlorine.

**BAUXITE, $Al_2O(OH)_4$.**

Crystallization unknown. Commonly shows a pisolitic or oölitic structure with rounded, concretionary grains embedded in an amorphous or clay-like mass (Fig. 502).

Hardness 1 to 3. Specific gravity 2.55. May be white, brown, yellow, or reddish in color. Argillaceous odor. Variable streak. Dull to earthy luster.

$Al_2O(OH)_4$. The composition varies greatly, aluminum oxide being as low as 40 per cent. or as high as 70 per cent. Ferric oxide, water, silica, and titanium oxide are usually present in varying amounts.

Bauxite is a decomposition product of feldspathic rocks, such as granites, syenites, gneisses, etc., the structure of the rocks being sometimes well preserved. It is one of the principal constituents of *laterite*, which is quite abundant in tropical regions. Bauxite is also found in nodules, grains, and pockets of irregular shape in limestones and dolomites, probably the result of deposition from hot solutions.

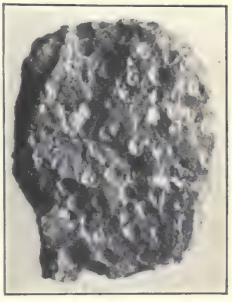


FIG. 502.—Pisolitic bauxite. Linwood, Georgia.

The most important deposits of bauxite in the United States are found in Pulaski and Saline Counties, Arkansas, the town of Bauxite being the chief center; also in a belt extending from Jacksonville, Alabama, to Adamsville, Georgia, Tennessee; in the departments of Languedoc and Provence, southeastern France; Nassau, Germany; Ireland.

Bauxite is used in the manufacture of aluminum, alum, bauxite brick, and the artificial abrasive called *alundum*.

**LIMONITE** (*Brown Hematite*), **$Fe_2O_3.H_2O$.**

Probably amorphous. Nearly always found in compact, porous, or earthy masses. Often stalactitic (Fig. 503), botryoidal, or mammillary. Radial fibrous structure and black varnish-like surfaces are quite characteristic (Fig. 504). Also concretionary.

Hardness 1 to 5.5. Specific gravity 3.4 to 4. May be yellowish, brown, or black in color. Streak always yellow brown. Conchoidal to earthy fracture.

$Fe_2O_3.H_2O$. Often impure, containing silica, clay, manganese oxide, and organic matter. Common as a pseudomorph after iron minerals, especially pyrite, marcasite, and siderite.

The important varieties are:—

1. *Compact Limonite.*—This includes the compact massive, stalactitic, botryoidal, and other varieties which often possess a radial fibrous structure and smooth varnish-like surfaces.

2. *Bog Iron Ore.*—Found in marshy and swampy places. More or less loose and porous in texture and may contain organic remains.

3. *Ochreous Limonite.*—Here are placed the earthy, yellow or brownish varieties, which may be quite impure on account of the admixture of clay and sand.

Limonite is the usual decomposition product of iron minerals, resulting through the action of water, carbon dioxide, humus acid, and oxygen. It is hence found very extensively, and usually in association with such minerals as pyrite, hematite, magnetite, and siderite, and also with many of the more strictly rock-forming minerals containing iron in small quantities, as the amphiboles and pyroxenes. *Residual limonite* may be the result of the decomposition of veins containing iron disulphide, or of the weathering of iron-bearing rocks. Such limonite is usually associated with slates, schists, or limestones. It occurs extensively

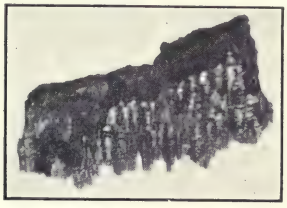


FIG. 503.—Stalactitic limonite. White Marsh, Pennsylvania.

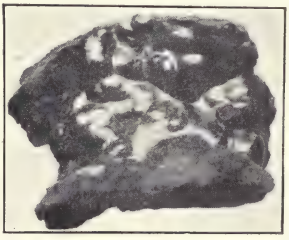


FIG. 504.—Limonite with varnish-like surface. Salisbury, Connecticut.

in the United States in a belt extending from Vermont to Alabama, the principal mines being in Alabama, Virginia, West Virginia, Tennessee, and Georgia. It is also found in Texas, Iowa, Wisconsin, Minnesota, and Oregon. Very common as the yellow coloring matter of clays and soils, and the brownish, rusty stain on rocks.

Constitutes about 4 per cent. of the iron ore mined in the United States. Also used as yellow ocher, burnt umber, and sienna in paints.

### 4. HALOIDS

The following are the four most important halogen minerals.

| | | |
|---|---|---|
| **HALITE** | **NaCl** | Cubic |
| **Cerargyrite** | **AgCl** | Cubic |
| **FLUORITE** | **$CaF_2$** | Cubic |
| **Cryolite** | **$Na_3AlF_6$** | Monoclinic |

Halite and cerargyrite are isomorphous.

**HALITE** (*Common Salt, Rock Salt*), **NaCl.**

Cubic, hexoctahedral class. Crystals are generally cubes, sometimes in combination with the octahedron; also skeletal or hopper-shaped.

Usually in cleavable, fibrous, or granular masses (Fig. 505); as an efflorescence in arid regions.

Excellent cubical cleavage. Hardness 2 to 2.5. Specific gravity 2.1 to 2.3. Colorless or white; when impure often reddish, blue, gray, greenish, or black. The color may be unevenly distributed. Easily soluble in water, one part in 2.8 parts of water. Saline taste. Vitreous luster. Transparent to translucent.

NaCl. Sometimes very pure. May contain varying amounts of the chlorides and sulphates of calcium and magnesium, also admixtures of gypsum, anhydrite, organic matter, clay, and occluded liquids and gases. Colors the flame intensely yellow.

Halite occurs very widely distributed. There are four methods of occurrence: (1) *Deposits*, often of great thickness and extent; (2) *In solution;* (3) *Efflorescence;* (4) *Sublimation product.*

1. *Deposits.*—Here salt is generally associated with gypsum, anhydrite, clay, or dolomite, and is found in sedimentary rocks of all ages. Some

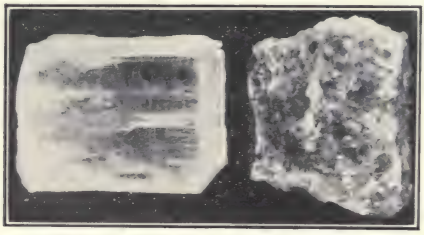


FIG. 505.—Halite. Cleavage cube, Stassfurt, Germany; granular, Retsof, New York.

of these deposits extend over large areas and may be of great thickness. Thus, the aggregate thickness of the salt layers in central New York is over 300 feet; near Detroit, Michigan, 400 feet; Stassfurt, Germany, over 1,200 feet; Petite Anse, Louisiana, over 2,000 feet.

Many explanations have been offered for the formation of extensive salt deposits, of which the *bar theory* of Ochsenius is perhaps in the larger number of cases the most satisfactory. This theory assumes that a portion of the ocean has been cut off from the main body of water by a bar, which rises almost to the surface. Evaporation within this bay would, on account of the shallowness of the water, be greatest on or near the bar. This would cause the water to become more dense and a portion would settle to the bottom behind the bar, causing the water of the bay to become strongly saline. In due time the concentration of this saline solution would be sufficient to cause the deposition of the various salts in order of their solubility. Gypsum being one of the least soluble is generally deposited first, followed by rock salt. As the evaporation continues more water would flow into the bay from the open ocean, thus furnishing a constant supply. If the bar emerges and cuts off the

bay entirely, continued evaporation would cause the deposition of not only calcium sulphate and rock salt, but also of the more soluble magnesium and potassium compounds, many of which are very complex. The salt deposits at Stassfurt, Germany, which cover an area of about 100 square miles, illustrate the order in which deposition will take place. These are underlain by clay and gypsum, and contain over thirty different minerals. Of these minerals, aside from halite, carnallite ($KCl.MgCl_2.6H_2O$), sylvite (KCl), and kainite ($MgSO_4.KCl.3H_2O$) are the most important and in commerce and industry are frequently known as *potash salts.*

In the United States rock salt has been mined at Livonia, New York; Oakwood, near Detroit, Michigan; Petite Anse, Louisiana; Lyons, Kansas; and in Sevier County, Utah.

2. *In Solution.*—Common salt occurs abundantly in solution in the ocean, salt lakes, and saline springs and wells. Most of the large quantities of salt produced is usually obtained by the evaporation of saline solutions.

3. *Efflorescence.*—Earthy crusts of salt are frequently found in arid regions; thus, in the steppes, near the Caspian Sea, and in Africa and Chile.

4. *Sublimation Product.*—Near volcanoes salt is sometimes found as the result of sublimation.

Salt is used extensively for household and dairying purposes, in meat and fish-packing, in the manufacture of sodium and its compounds, in various metallurgical processes, and to glaze pottery. Sodium carbonate or soda ash is used in large quantities in glass and soap making; sodium bicarbonate for cooking and baking and in medicine; and sodium cyanide in the cyanide process for the extraction of gold. New York, Michigan, Ohio, Kansas, Louisiana, Virginia, California, West Virginia, Texas, and Utah produce enormous quantities of salt annually. Of these, the first five furnish about 95 per cent. of the total production of the United States.

**Cerargyrite** (*Horn Silver*), **AgCl.**

Cubic, hexocathedral class. Crystals are rare and poorly developed. Generally found as a waxy crust or coating, also stalactitic and dendritic.

No cleavage. Highly sectile, cutting easily, and yielding shiny surfaces. Resembles wax. Very soft. Hardness 1 to 1.5. Specific gravity, 5.5. Pearly gray, yellowish, greenish, or white in color; on exposure to light turns violet, brown, or black. Transparent to translucent. When rubbed becomes shiny. Waxy or resinous luster.

AgCl. May contain mercury, ferric oxide, or other impurites. Fuses easily on charcoal and yields a globule of silver.

Found as an alteration product in the upper levels of silver deposits.

The usual associates are the various silver minerals, also galena, limonite, calcite, barite, and cerussite. It has been observed in Saxony, Norway, Mexico, Peru, Chile; also at Broken Hill, New South Wales; near Leadville, Colorado; Comstock Lode, Nevada; Poor Man's Lode, Idaho; Lake Valley, New Mexico; Cobalt, Ontario.

An important ore of silver.

**FLUORITE** (*Fluor Spar*), $CaF_2$.

Cubic, hexoctahedral class. Excellent crystals are common. The usual form is the cube (Fig. 506), either alone or in combination

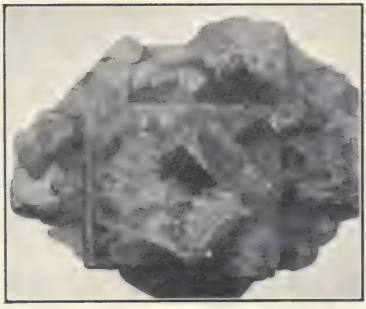


FIG. 506.—Fluorite, Cumberland, England.

FIG. 507.—Fluorite (penetration cubes). Durham, Weardale, England.

with the tetrahexahedron or hexoctahedron. Penetration cubes twinned according to the Spinel law are frequently observed (Fig. 507). Also in cleavable, granular, and fibrous masses.

Excellent octahedral cleavage (Fig. 508). Hardness 4. Specific gravity 3 to 3.2. Usually greenish, yellowish, or bluish in color; also various shades of red or brown, white, and colorless. Sometimes multicolored. Transparent to nearly opaque. Vitreous luster. Frequently strongly fluorescent, and phosphorescent when heated.

FIG. 508.—Fluorite (octahedral cleavage). Near Rosiclare, Illinois.

$CaF_2$. Usually quite pure.

Fluorite is found in veins in limestones and dolomites, less frequently in granitic rocks and sandstones. It is also a common gangue mineral with ores or lead, silver, copper, and especially tin. The common associates are galena, sphalerite, cassiterite, calcite, quartz, barite, pyrite, chalcopyrite, topaz, tourmaline, and apatite. Excellent crystals occur at Cumberland, Cornwall, and Derbyshire, England. Large quantities are mined annually in Hardin County, Illinois, and Crittenden and Livingstone counties, Kentucky.

Smaller amounts are obtained from New Hampshire, Colorado, Arizona, and New Mexico. Fluorite is a common mineral and occurs widely distributed.

Fluorite is used extensively in the manufacture of open hearth steel, iron and steel enamel ware, opalescent glass, cyanamide, hydrofluoric acid, and in the electrolytic refining of antimony and lead.

**CRYOLITE** (*Ice-stone*), $Na_3AlF_6$.

Monoclinic, prismatic class. Crystals are cubical in habit. Usually observed in compact, granular, or cleavable masses (Fig. 509).

Basal and prismatic cleavages, three directions nearly at right angles. Uneven fracture. Hardness 2.5 to 3. Specific gravity 2.9 to 3. Colorless to snow-white, more rarely reddish, brownish, or black. Pearly luster on the basal pinacoid, elsewhere vitreous to greasy. Often resembles snow ice or paraffin. Transparent to translucent.

$Na_3AlF_6$. Usually quite pure. Fuses easily and imparts a yellow color to the flame.

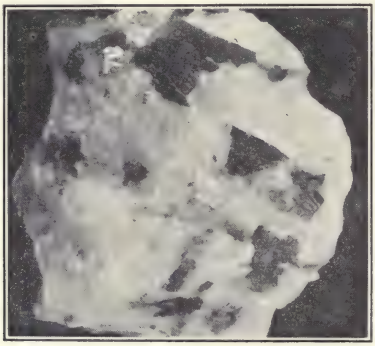


FIG. 509.—Cryolite (white) and siderite. Ivigtut, Greenland.

The only important occurrence of cryolite is at Ivigtut on the southern coast of Greenland, where it is found in veins in granite, and is associated with siderite, chalcopyrite, galena, pyrite, fluorite, sphalerite, columbite, cassiterite, and molybdenite. Found also at Miask in the Ural Mountains, and in the Pike's Peak district, Colorado.

Used principally as a bath in the manufacture of aluminum by the electrolytic process; thus, at Niagara Falls, New York; also in opalescent glasses and enamels, and white Portland cement.

### 5. NITRATES, CARBONATES AND MANGANITES

#### (*a*) Nitrate

Soda niter or Chile saltpeter is the only nitrate occurring in nature in sufficient quantities to warrant a description.

**SODA NITER** (*Chile Saltpeter*), **$NaNO_3$.**

Hexagonal, ditrigonal scalenohedral class. Crystals resemble those of calcite, but are rare. Generally in crystalline aggregates or grains, also in crusts or deposits of great extent.

Perfect rhombohedral cleavage. Conchoidal fracture. Hardness 1.5 to 2. Specific gravity 2.1 to 2.3. Vitreous luster. Colorless, white, yellowish, gray, or reddish brown. Transparent to nearly opaque. Cooling and saline taste.

$NaNO_3$. Usually contains some sodium chloride and sodium sulphate. Easily soluble in water. Absorbs moisture. Colors flame intensely yellow. Mixed with rock salt, guano, gypsum, clay, and sand, it occurs in extensive deposits, 6 to 12 feet thick, in the deserts of Atacama and Tarapaca in northern Chile. The crude material is called *caliche*, and must contain about 50 per cent. sodium nitrate to be considered high grade. Smaller quantities also occur in San Bernardino and Inyo Counties, California; Humboldt County, Nevada; and in New Mexico.

Soda niter is a very important commercial mineral. It is used extensively as a fertilizer, in the manufacture of nitric and sulphuric acid and potassium nitrate. It is also a source of iodine, which is present in small amounts as lautarite ($Ca(IO_3)_2$).

### (*b*) Carbonates

Some of the most widely distributed minerals are carbonates. Several of them are of great importance commercially.

| | | |
|---|---|---|
| | CALCITE GROUP | |
| **CALCITE** | $CaCO_3$ | Hexagonal |
| **DOLOMITE** | $CaMg(CO_3)_2$ | Hexagonal |
| **MAGNESITE** | $MgCO_3$ | Hexagonal |
| **SMITHSONITE** | $ZnCO_3$ | Hexagonal |
| **RHODOCHROSITE** | $MnCO_3$ | Hexagonal |
| **SIDERITE** | $FeCO_3$ | Hexagonal |
| | ARAGONITE GROUP | |
| **ARAGONITE** | $CaCO_3$ | Orthorhombic |
| **STRONTIANITE** | $SrCO_3$ | Orthorhombic |
| Witherite | $BaCO_3$ | Orthorhombic |
| **CERUSSITE** | $PbCO_3$ | Orthorhombic |
| | MALACHITE GROUP | |
| **MALACHITE** | $CuCO_3.Cu(OH)_2$ | Monoclinic |
| **AZURITE** | $2CuCO_3.Cu(OH)_2$ | Monoclinic |

The calcite and aragonite groups form an isodimorphous series.

$CaCO_3$ is dimorphous with modifications in the hexagonal and orthorhombic systems, known as calcite and aragonite, respectively.

#### Calcite Group

This group contains six members, of which calcite is the most common and important. All of these minerals possess a perfect rhombohedral cleavage.

**CALCITE** (*Calcspar*), $CaCO_3$.

Hexagonal, ditrigonal scalenohedral class. Commonly in good crystals; often very complex. The habit varies greatly and may be obtuse or

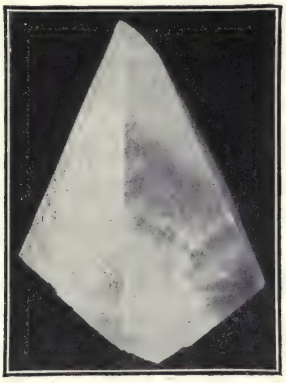


FIG. 510.—Calcite (scalenohedron). Joplin, Missouri.

FIG. 511.—Calcite. Cumberland, England.

acute rhombohedral, tabular, long prismatic, or scalenohedral (Figs. 510 and 511). Over 300 forms have been observed. Twins are relatively common. The two most important laws involve twinning parallel

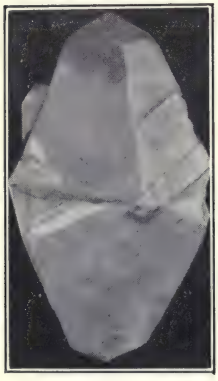


FIG. 512.—Calcite (twinned parallel to the base). Guanajuato, Mexico.

FIG. 513.—Calcite (twinned parallel to $-\frac{1}{2}$ R). Joplin, Missouri.

to (1) the basal pinacoid (Fig. 512), and (2) the negative rhombohedron ($-\frac{1}{2}R$) (Fig. 513). Calcite also occurs in granular, lamellar, fibrous, compact, porous, or earthy masses; less frequently it is oölitic, pisolitic, or stalactitic.

The highly perfect rhombohedral cleavage (105°) is very characteristic. Hardness 3. Specific gravity 2.72. Vitreous to earthy luster. Commonly colorless, white, or yellowish, but may be any color. Transparent to opaque. Transparent varieties show strong double refraction (Fig. 514).

$CaCO_3$. Sometimes very pure. May contain varying amounts of magnesium, iron, or manganese replacing the calcium. Often mixed with limonite, hematite, organic matter, sand, or clay. Easily soluble with a brisk effervescence in cold dilute acids. This test serves to distinguish calcite from dolomite, which does not effervesce in cold acid. Calcite may be distinguished from aragonite by *Meigen's test*, which consists of boiling the powdered minerals in a solution of cobalt nitrate. When

FIG. 514.—Calcite: Variety, Iceland spar, showing double refraction. Big Timber, Montana.

calcite is treated in this way, the powder remains unchanged or turns a pale yellow, while aragonite assumes a lilac-red color.

The different varieties of calcite may be grouped as follows: (*a*) *ordinary calcites*, (*b*) *limestones*, (*c*) *marbles*, (*d*) *chalk and marl*, and (*e*) *spring, stream, and cave deposits.*

(*a*) **Ordinary Calcites.**—These include crystals, and cleavable, fibrous, and lamellar masses.

1. *Dog-tooth Spar.*—Scalenohedral crystals, often in beautiful aggregates (Fig. 510).

2. *Nail-head Spar.*—Prismatic crystals with obtuse rhombohedral terminations (Fig. 511).

3. *Iceland Spar.*—Colorless and transparent, showing strong double refraction (Fig. 514).

4. *Satin Spar.*—A fibrous variety with a silky luster. This term is also applied to fibrous gypsum, pages 264 and 265.

(*b*) **Limestones.**—Calcite is the chief constituent of the limestone rocks, which occur so widely distributed. They are massive, and may

be dull and compact, coarse or fine granular, or composed of fragmental material.

1. *Compact Limestones.*—These may be nearly white, yellow, bluish gray, reddish, or black in color.

2. *Magnesian or Dolomitic Limestones.*—As the name indicates, these limestones contain varying percentages of magnesium carbonate.

3. *Lithographic Limestones.*—An even-grained, compact limestone, suitable for lithographic purposes. That from Solenhofen, Bavaria, is buff or drab in color.

4. *Hydraulic Limestones.*—These are impure limestones, containing from 10 to 40 per cent. of clayey impurities. They are used extensively in the manufacture of cement.

5. *Bituminous Limestones.*—Owing to the presence of much organic matter, these limestones yield the characteristic odor of bitumen when struck a blow with a hammer.

FIG. 515.—Calcite: Variety, coquina. Anastatia Island, Florida.

6. *Coquina.*—This is a mass of shell remains (Fig. 515). Found along the coast of Florida, near St. Augustine.

7. *Oölitic Limestones.*—These are composed of small, spherical concretions, resembling fish-roe.

8. *Pisolitic Limestones.*—The concretions are larger, and about the size of a pea.

(*c*) **Marbles.**—These possess a fine to coarse crystalline structure, and are metamorphosed limestones (Fig. 516). Commercially, however, any calcareous rock capable of taking a polish and suitable for decorative and structural purposes is termed a marble.

(*d*) **Chalk and Marl.**—These are soft earthy varieties.

1. *Chalk.*—Soft, white or grayish, earthy masses, consisting principally of the remains of foraminifera. Found in large deposits at Dover, England.

2. *Marl.*—A soft, calcareous deposit mixed with clay and sand. Often contains shell or organic remains. It is used in the manufacture of cement.

(*e*) **Spring, Stream, and Cave Deposits.**—These are due largely to the escape of carbon dioxide, which causes the soluble calcium bicarbonate, $CaH_2(CO_3)_2$, to pass over to the more insoluble normal carbonate, $CaCO_3$, and be deposited. It is thought that certain algæ aid in this process.

1. *Travertine, Calcareous Sinter, or Calc Tufa.*—These occur around springs and in stream beds, and are usually porous and often contain twigs, leaves, and other organic remains.

2. *Stalactites.*—Icicle-like forms suspended from the roofs of caves.

3. *Stalagmites.*—Deposits on the floors of caves, usually conical in shape.

4. *Onyx Marble.*—Compact deposits with a crystalline structure, often banded, translucent, and of colors suitable for decorative purposes (Fig. 517).

Calcite occurs very widely distributed. As limestone, marble, chalk, and marl it is found in large deposits, often of great thickness and extending over wide areas. It is also abundant as deposits around springs and in streams, and in cracks and cavities in igneous and sedimentary rocks. Often observed as an associate of metalliferous ore deposits. Excellent crystals are very common. A few of the most noted localities are: Eskifiord, Iceland; Derbyshire, Cumberland, Devonshire, Durham, Lancashire, England; Andreasberg, Germany; Kapnik, Hungary; Guanajuato, Mexico; Joplin, Missouri; Rossie, St. Lawrence County, New York; Lake Superior copper district. Large and commercially important deposits of marble occur in Vermont, New York, Tennessee, Georgia, Maryland, and Colorado.

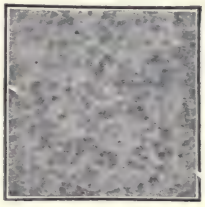


FIG. 516.—Marble. Near Tate, Georgia.

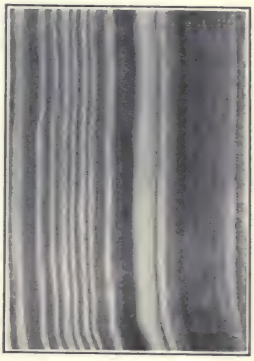


FIG. 517.—Calcite: Variety, Mexican onyx. Lehi City, Utah.

The different varieties of calcite are commercially of great value. Iceland spar is used in optical instruments; limestone for building purposes, quicklime, cement, flux in various metallurgical processes, railroad ballast, macadam, in lithography, and concrete; marble for building, ornamental, monumental, and statuary purposes, and as a source of carbon dioxide; chalk for whiting, crayon, scouring and polishing preparations, and as an adulterant; marl for cement.

**DOLOMITE** (*Pearl Spar*), $\mathbf{CaMg(CO_3)_2}$.

Hexagonal, trigonal rhombohedral class. Rhombohedral crystals are common. The faces are frequently curved forming saddle-shaped crystals (Fig. 518). Also in fine to coarse grained, cleavable, or compact masses.

Perfect rhombohedral cleavage. Hardness 3.5 to 4. Specific gravity 2.9. White, reddish, yellow, brown, or black; rarely colorless. Vitreous to pearly luster. Transparent to translucent.

$CaMg(CO_3)_2$.—In the crystals of dolomite the carbonates of calcium and magnesium are usually present in the proportion of 1 : 1; in massive varieties this ratio varies greatly, but $CaCO_3$ generally predominates. In many instances dolomite is believed to have been formed by the action of soluble magnesium salts upon calcium carbonate, either before or after emergence from the sea.

$$2CaCO_3 + MgCl_2 = CaMg(CO_3)_2 + CaCl_2$$

Fragments of dolomite are but slightly acted upon by cold dilute acid; the powder effervesces briskly with hot dilute acids.

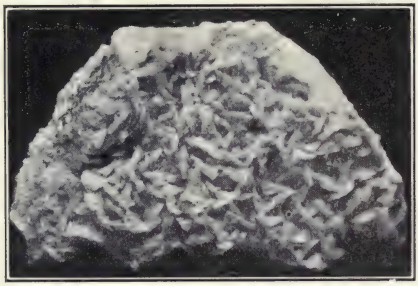


Fig. 518.—Dolomite. Joplin, Missouri.

Dolomite occurs abundantly in many ore deposits, and in cavities of various igneous and sedimentary rocks. Thus, at Joplin, Missouri; Lockport, New York; Austria; Switzerland; Freiberg, Saxony. The compact granular variety occurs in deposits of great thickness and extent. Thus, some of the mountain ranges of central Europe are principally dolomite. These crystalline dolomites grade into dolomitic and magnesian limestones, see page 244.

Dolomite is used for building, statuary, monumental, and ornamental purposes; as a source of magnesium compounds; and as refractory material.

**MAGNESITE, $MgCO_3$.**

Hexagonal, ditrigonal scalenohedral class. Rarely in rhombohedral crystals; usually in granular, compact, or earthy masses resembling unglazed porcelain (Fig. 519). Also coarsely crystalline resembling coarse dolomite or marble in texture.

Crystals have a rhombohedral cleavage. Conchoidal fracture is conspicuous on massive varieties. Brittle. Hardness 3.5 to 4.5. Specific gravity 2.9 to 3.1. Colorless, white, yellow, brown, or blackish. Vitreous to dull luster. Transparent to opaque.

$MgCO_3$. Iron or calcium may be present. Powdered magnesite is soluble in hot dilute acids.

Magnesite is commonly the result of the hydration and carbonatization of magnesium. Thus, olivine, $(Mg,Fe)_2SiO_4$, may alter to magnesite,

serpentine, limonite, and opal. It is found in veins in talcose and chloritic schists and in serpentine. It occurs in Moravia and Styria, Austria; Silesia; Zillerthal, Tyrol; Greece; and very extensively in Santa Clara, Sonoma, Napa, Kern, Fresno, and San Benito counties, California, and in Stevens County, Washington.

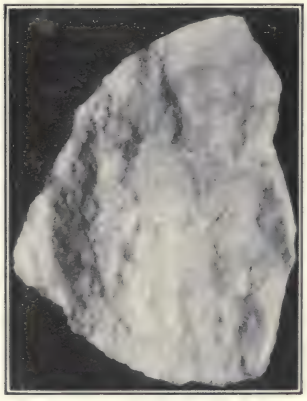


FIG. 519.—Magnesite. Tulare County, California.

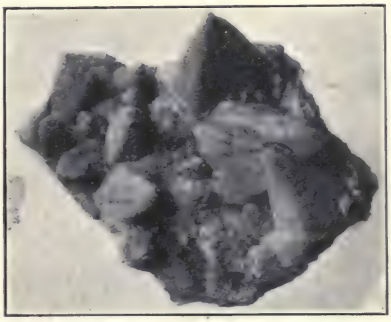


FIG. 520.—Smithsonite (pseudomorph after calcite). Mineral Point, Wisconsin.

Magnesite is used chiefly in the manufacture of refractory bricks, crucibles, furnace hearths, oxychloride or Sorel cement, and magnesium sulphite for the digestion and whitening of wood-pulp paper; as a source of carbon dioxide and magnesium compounds; when mixed with asbestos it serves as a boiler and steam-pipe covering.

**SMITHSONITE** (*Calamine, Dry Bone*), $ZnCO_3$.

Hexagonal, ditrigonal scalenohedral class. Crystals are usually small, and rough or curved. Generally found in reniform, botryoidal, stalactitic, or compact granular masses. *Dry bone* is a term given to cellular and porous varieties.

Rhombohedral cleavage, observed on crystals. Uneven to splintery fracture. Hardness 5. Specific gravity 4.1 to 4.5. Color is commonly gray or brown; also white, yellow, blue, green, and pink. Translucent to opaque. Vitreous to pearly luster.

$ZnCO_3$. Iron, manganese, calcium, and magnesium may be present. *Turkey fat* is yellow smithsonite containing greenockite, CdS. Common as a pseudomorph after calcite, especially, at Mineral Point, Wisconsin (Fig. 520).

Smithsonite is a secondary mineral and occurs extensively in the upper levels in limestones and dolomites. It is often the result of the action of carbonated waters on other zinc minerals. The common associates are sphalerite, hemimorphite, galena, limonite, and calcite. Sometimes it is mixed with sand and clay. Occurs at Broken Hill, New South Wales;

Laurium, Greece; Hungary; Scotland; Kelly, New Mexico; also extensively in Missouri, Arkansas, Iowa, Wisconsin, and Virginia, where it is mined as zinc ore. The term *calamine* is sometimes applied to smithsonite, but it refers more properly to hemimorphite, $H_2Zn_2SiO_5$, page 280. These two minerals often occur in intimate association.

Chiefly used as an ore of zinc; green, blue, and yellowish varieties are sometimes polished for gem and ornamental purposes.

**RHODOCHROSITE, $MnCO_3$.**

Hexagonal, ditrigonal, scalenohedral class. Crystals are rhombohedral in habit, small, and quite rare (Fig. 521). Generally in cleavable, granular, and botryoidal masses; also in crusts.

Perfect rhombohedral cleavage. Uneven fracture. Hardness 3.5 to 4.5. Specific gravity 3.3 to 3.6. Usually rose-red or pink in color; also gray, dark brown, and more rarely colorless. Vitreous to pearly luster. Translucent.

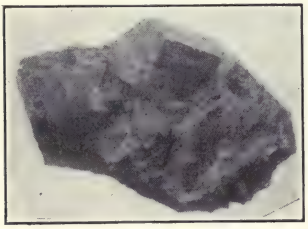


FIG. 521.—Rhodochrosite (Rhombohedrons). Lake County, Colorado.

FIG. 522.—Siderite (dark) with dolomite. Salzburg, Austria.

$MnCO_3$. Calcium, iron, zinc, and magnesium are often present replacing the manganese. Occurs as a pseudomorph after calcite and fluorite.

Usually found with iron, lead, gold, silver, copper ores; and other manganese minerals. Most common associates are galena, sphalerite, pyrite, rhodonite, and psilomelane; thus, at Hucha, Spain; Freiberg, Saxony; Kapnik, Hungary; Franklin Furnace, New Jersey; Alicante, Colorado; Butte, Montana; Austin, Nevada.

Rhodochrosite is not a very common mineral. It is sometimes used as a source of manganese and its compounds.

**SIDERITE,** (*Spathic Iron, Chalybite*) **$FeCO_3$.**

Hexagonal, ditrigonal scalenohedral class. Distorted and curved rhombohedral crystals (saddle-shaped) are quite common (Fig. 522). Usually found in cleavable, granular, botryoidal, or fibrous masses.

Perfect rhombohedral cleavage. Conchoidal fracture. Hardness 3.5 to 4.5. Specific gravity 3.7 to 3.9. Vitreous to pearly luster. Usually brownish to nearly black in color; also gray, green, and white. Translucent to nearly opaque. Streak white or yellowish.

$FeCO_3$. Usually contains some $CaCO_3$ and $MnCO_3$. Manganiferous varieties are termed *oligonite*. When mixed with clay, sand, and organic matter, it is often called *clay ironstone* or *blackband*. Occurs as a pseudomorph after calcite, aragonite, dolomite, barite, and fluorite. It alters to limonite, hematite, and magnetite.

Siderite occurs commonly with sulphide ore deposits, also in beds and as concretions in limestones and shales. The common associates are pyrite, chalcopyrite, galena, tetrahedrite, and cryolite. It occurs with ore deposits in the Hartz Mountains; Pribram, Bohemia; Cornwall, England; Freiberg, Saxony; with cryolite and chalcopyrite in southern Greenland; in beds and as concretions in Westphalia; southern Wales; Silesia; Roxbury, Connecticut; St. Lawrence County, New York; in the coal measures in eastern Ohio, Kentucky, and western Pennsylvania.

A minor ore of iron. If it contains considerable manganese, it is used for spiegeleisen.

## Aragonite Group

The members of this group crystallize in the orthorhombic system. The prism angle of these minerals approximates 120°, so that crystals frequently have a pseudohexagonal development.

### ARAGONITE, $CaCO_3$.

Orthorhombic, bipyramidal class. Crystals are quite common and show great diversity in development. They may be (1) domatic or

FIG. 523.—Aragonite (trillings). Girgenti, Sicily.

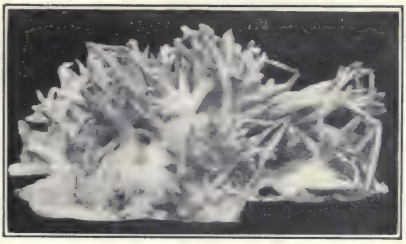


FIG. 524.—Aragonite: Variety, flos ferri. Styria, Austria.

chisel-like, (2) acute pyramidal or spear-shaped, and (3) prismatic and pseudohexagonal, consisting of a prism and striated base. The prism angle is 116° 16′. This pseudohexagonal symmetry is often accentuated by twinning parallel to a face of the unit prism (Fig. 523). Contact, cyclic, and penetration twins are common. Also occurs in radial, branching, columnar, and fibrous aggregates; oölitic, globular, stalactitic, and in crusts.

Imperfect brachypinacoidal and prismatic cleavages. Conchoidal fracture. Hardness 3.5 to 4. Specific gravity 2.9 to 3. Most commonly colorless, white, or yellow; also reddish, bluish, or black. Greasy luster on fracture surfaces, elsewhere vitreous. Transparent to translucent.

$CaCO_3$. May contain some strontium. Effervesces easily with acids, but not as easily as calcite. Massive varieties are easily distinguished from calcite by Meigen's test, see page 169. Occurs as a pseudomorph after gypsum and calcite, but calcite pseudomorphs after aragonite are more abundant. At about 470°C., aragonite changes to calcite. Aragonite is usually deposited from hot solutions while calcite is formed from cold solutions. It may also be formed at ordinary temperatures through the action of organic agencies, or by precipitation from saline waters containing sulphates.

Aragonite is found (1) in cracks and cavities, often associated with the zeolites. (2) In ore deposits, especially iron ore. The coralloidal variety occurring with siderite at Hüttenberg, Carinthia, is termed *flos ferri* (Fig. 524). (3) Disseminated in clay, associated with gypsum, sulphur, and celestite. (4) As a deposit from hot springs and geysers, sometimes pisolitic and in crusts. (5) It constitutes the pearly layer of many shells and pearls. Aragonite is not nearly as common as calcite. Excellent crystals are found at Herrengrund, Hungary; Bilin, Karlsbad, and Horschenz, Bohemia; Aragon, Spain; Girgenti, Sicily; Alton Moor, England; other varieties at Hoboken, New Jersey; Lockport, New York; Warsaw, Illinois; Organ Mountains, New Mexico.

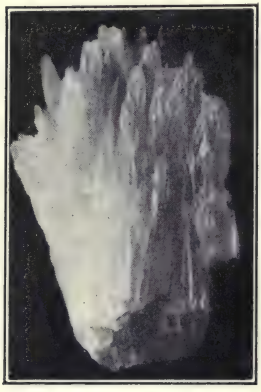


FIG. 525.—Strontianite. Dreisteinfurt, Westphalia, Germany.

Aragonite is of no importance commercially.

## STRONTIANITE, $SrCO_3$.

Orthorhombic, bipyramidal class. Crystals are usually spear-shaped or acicular and arranged in radial aggregates. Forms and twinning are similar to those of aragonite. Pseudohexagonal with a prism angle of 117° 19′. Also granular and compact, sometimes with a radial fibrous structure (Fig. 525).

Imperfect prismatic cleavage. Conchoidal fracture. Hardness 3.5 to 4. Specific gravity 3.6 to 3.8. Colorless, white, gray, yellow, and green. Vitreous luster, greasy on fracture surfaces. Transparent to translucent.

$SrCO_3$. Usually contains some calcium and barium. Occurs as a pseudomorph after celestite.

Occurs in ore deposits, commonly with barite and galena. Important localities are: Strontian, in Argyllshire, Scotland; Hamm in Westphalia,

Germany; Schoharie, New York; Ida, Michigan; near Austin, Texas; Skagit County, Washington.

Strontianite is a source of strontium compounds, some of which are used extensively. The oxide and hydroxide are of importance in the precipitation of sugar from molasses; the nitrate, carbonate, and oxalate are used for red fire; and the iodide, bromide, and lactate in medicine.

**Witherite, $BaCO_3$.**

Orthorhombic, bipyramidal class. Usually in pseudohexagonal bipyramids, resembling quartz (Fig. 526). These are penetration trillings with the twinning plane parallel to the unit prism. The prism angle is 117° 48′. Parallel groups not uncommon. Also in compact, botryoidal, reniform, or globular masses; sometimes with a lamellar or radial fibrous structure.

Fig. 526.—Witherite (trillings). Northumberland, England.

Imperfect prismatic cleavage. Uneven fracture. Hardness 3.5. Specific gravity 4.2 to 4.35. Colorless, grayish, white, or yellowish. Vitreous luster, on fracture surfaces somewhat greasy. Translucent to transparent.

$BaCO_3$. Usually quite pure.

Occurs with deposits of galena in northwestern England; thus, at Fallowfield, Northumberland; Durfton, Westmoreland; Alston Moor, Cumberland; with barite at Freiberg, Saxony; Lexington, Kentucky; Thunder Bay district, Lake Superior.

Witherite is used to adulterate white lead and in the extracting of sugar from sugar-beets.

**CERUSSITE** (*White Lead Ore*), **$PbCO_3$.**

Orthorhombic, bipyramidal class. Crystals are generally tabular, prismatic, or pyramidal in habit; frequently arranged in clusters or star-shaped groups. Often very complex. Pronounced pseudohexagonal symmetry, the prism angle being 117° 14′. Twins are very common and similar to those of aragonite. Also in granular, fibrous, and compact masses, interlaced bundles (Fig. 527) and stalactitic.

Fig. 527.—Cerussite. Leadville, Colorado.

Hardness 3 to 3.5. Specific gravity 6.4 to 6.6. Generally colorless, white, or gray. Adamantine luster, sometimes silky. Transparent to almost opaque.

$PbCO_3$. At times contains some silver and zinc. Occurs as a pseudomorph after galena and anglesite.

Found usually in the upper levels of galena deposits, from which it

has resulted by the action of carbonated waters. Common associates are galena, pyromorphite, anglesite, malachite, and limonite. Occurs at Broken Hill, New South Wales; Leadhills, Scotland; various places in Mexico; Leadville, Colorado; Pima and Yuma counties, Arizona; Park City, Utah; Coeur d'Alene district, Idaho.

An important ore of lead and silver.

### MALACHITE GROUP

This group includes two basic carbonates of copper, which are of great importance commercially.

**MALACHITE** (*Green Carbonate of Copper*), $CuCO_3.Cu(OH)_2$.

Monoclinic, prismatic class. Crystals are usually acicular, very slender, and without good terminations; often arranged in groups or tufts. Commonly in reniform, botryoidal, and stalactitic masses with smooth surfaces and a banded or radial fibrous structure (Fig. 528); also earthy and in velvety crusts.

Conchoidal to splintery fracture. Hardness 3.5 to 4. Specific gravity 3.7. to 4.1. Bright emerald green, grass green, to nearly black in color. Translucent to opaque. Silky, adamantine, or dull luster. Light green streak.

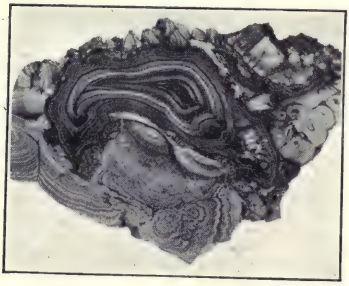


Fig. 528.—Malachite (polished). Rhodesia, Africa.

$CuCO_3.Cu(OH)_2$. Masses may contain the oxides of iron and manganese, clay, and sand. Occurs commonly as a pseudomorph after cuprite, azurite, and native copper.

Malachite is a common alteration product of copper minerals, resulting from the action of carbonated waters, and hence, is found in smaller or larger quantities in the upper levels of all copper mines. Common associates are azurite, cuprite, native copper, chalcocite, chalcopyrite, and bornite. Occurs in large quantities in the Ural Mountains; at Chessy, France, as pseudomorphs after cuprite; Cornwall, England; Rhodesia; Chile; Bisbee and Clifton districts, Arizona; Park City, Utah; as a coating on native copper in the Lake Superior copper district.

An important ore of copper, especially in Arizona. Also used in jewelry and for ornamental purposes, such as table tops and vases. *Malachite matrix* is a term given to polished specimens with admixtures of gangue material.

**AZURITE** (*Chessylite, Blue Carbonate of Copper*), $2CuCO_3.Cu(OH)_2$.

Monoclinic, prismatic class. Short prismatic or tabular crystals, often very complex, and arranged in spherical aggregates. Commonly

found in reniform or botryoidal masses, with a velvety, radial fibrous structure; also earthy and in crusts.

Hardness 3.5. Specific gravity 3.7 to 3.8. Vitreous to adamantine luster. Light azure to deep blue in color. Streak light blue. Translucent to opaque.

$2CuCO_3.Cu(OH)_2$. Occurs as a pseudomorph after cuprite and tetrahedrite. Alters to malachite.

Origin and occurrences are the same as for malachite; not as common as malachite. Excellent crystals occur at Chessy, France; Ural Mountains; Chile; Bisbee and Clifton copper districts, Arizona; also in Utah and California.

Used as an ore of copper. When intimately mixed with malachite, it is sometimes polished for gem purposes and sold as *azurmalachite*.

### (*c*) MANGANITES

These minerals contain large percentages of manganese, but the conposition of only one, hausmannite, is sufficiently constant to warrant the assigning of a chemical formula.

| | | |
|---|---|---|
| Hausmannite | Tetragonal | $Mn_2MnO_4$ |
| Psilomelane | Amorphous | $MnO_2$, BaO, $H_2O$,etc. |

Of these minerals psilomelane is the more common and important.

**Hausmannite**, $Mn_2MnO_4$.

Tetragonal, scalenohedral class. Crystals are acute pyramidal and often form cyclic twins. Found generally in granular to compact masses.

Perfect basal cleavage. Hardness 5 to 5.5. Specific gravity 4.7 to 4.8. Brownish black to black in color. Chestnut brown streak. Greasy metallic luster. Opaque.

$Mn_2MnO_4$. Soluble in hydrochloric acid with an evolution of chlorine.

A comparatively rare mineral. The common associates are pyrolusite, psilomelane, magnetite, barite, and hematite. Occurs at Ilfeld and Ilmenau, Germany; Pajsberg and Langban, Sweden.

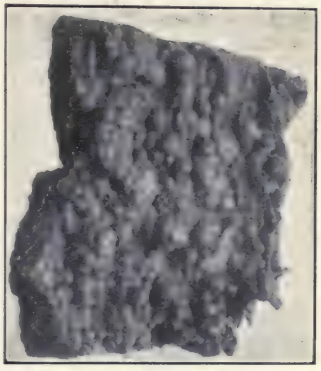


FIG. 529.—Psilomelane. Ironwood, Michigan.

**Psilomelane** (*Black Hematite*), $MnO_2$, BaO, $H_2O$, $K_2O$, etc.

Occurs only in botryoidal, reniform, or stalactitic masses, usually having smooth surfaces (Fig. 529).

Hardness 5 to 6, but may be soft superficially, due to a coating of pyrolusite. Specific gravity 3.7 to 4.7. Dark gray to iron black in color. Brownish black streak. Dull or submetallic luster. Opaque.

The composition varies greatly; $MnO_2$, 70 to 90 per cent.; BaO, 6 to 17 per cent.; $H_2O$, 1 to 6 per cent. It may also contain potassium, calcium, copper, and silicon. Evolves chlorine when treated with hydrochloric acid.

Psilomelane is a secondary mineral, and is always associated with other manganese minerals, limonite, or barite. Found at Ilfeld and Ilmenau, Germany; Cornwall, England; Brandon, Vermont; Batesville, Arkansas; Blue Ridge region, Virginia; Cartersville, Georgia.

One of the important ores of manganese.

### 6. SULPHATES, CHROMATES, MOLYBDATES, TUNGSTATES, AND URANATES

The minerals belonging to this division may be conveniently arranged in the following groups:

| | | |
|---|---|---|
| | BARITE GROUP | |
| **ANHYDRITE** | $CaSO_4$ | Orthorhombic |
| **CELESTITE** | $SrSO_4$ | Orthorhombic |
| **BARITE** | $BaSO_4$ | Orthorhombic |
| **ANGLESITE** | $PbSO_4$ | Orthorhombic |
| **Crocoite** | $PbCrO_4$ | Monoclinic |
| | WOLFRAMITE GROUP | |
| **Wulfenite** | $PbMoO_4$ | Tetragonal |
| **Scheelite** | $CaWO_4$ | Tetragonal |
| **Huebnerite** | $MnWO_4$ | Monoclinic |
| **WOLFRAMITE** | $(Fe,Mn)WO_4$ | Monoclinic |
| **Ferberite** | $FeWO_4$ | Monoclinic |
| **Uraninite** | $UO_3.UO_2,PbO$,etc. | Cubic |
| **ALUNITE** | $K_2(Al.2OH)_6(SO_4)_4$ | Hexagonal |
| **Brochantite** | $CuSO_4.3Cu(OH)_2$ | Orthorhombic |
| **GYPSUM** | $CaSO_4.2H_2O$ | Monoclinic |
| **Epsomite** | $MgSO_4.7H_2O$ | Orthorhombic |
| **Melanterite** | $FeSO_4.7H_2O$ | Monoclinic |
| **Chalcanthite** | $CuSO_4.5H_2O$ | Triclinic |

Most of these minerals possess non-metallic lusters.

#### Barite Group

This group may be subdivided into two series. One of these series has orthorhombic crystallization, the other monoclinic. Crocoite is the only representative of the second series.

**ANHYDRITE, $CaSO_4$.**

Orthorhombic, bipyramidal class. Crystals are prismatic or thick tabular in habit, but not common. Generally in granular, cleavable,

fibrous, or contorted masses. When granular may resemble marble or lumps of sugar (Fig. 530).

Pinacoidal cleavages in three directions at right angles, yielding cubic or rectangular fragments. Conchoidal fracture. Hardness 3 to 3.5. Specific gravity 2.7 to 3. Colorless, white, grayish, bluish, reddish, or black. Vitreous to pearly luster. Transparent to translucent.

$CaSO_4$. Often mixed with organic matter. Absorbs water and alters to gypsum, $CaSO_4.2H_2O$, causing an increase of 33 to 62 per cent. of the original volume. This hydration is, no doubt, the cause of the many local disturbances in the rock strata commonly observed in regions where gypsum occurs; thus, in central New York, and the Island of Put-in-Bay in Lake Erie. Occurs sometimes as a pseudomorph after gypsum.

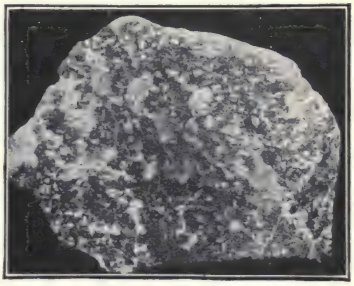


FIG. 530.—Anhydrite. Oakwood Salt Shaft, Detroit, Michigan.

Found commonly in limestones and shales associated with halite and gypsum. Some of the principal localities are: the Stassfurt salt district, Germany; Hall, Tyrol; Bex, Switzerland; Nova Scotia; New Brunswick; Lockport, New York; Detroit, Michigan; Ellsworth County, Kansas.

Anhydrite is of little use commercially. A silicious variety is sometimes cut and polished for ornamental purposes.

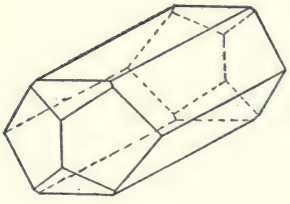


FIG. 531.

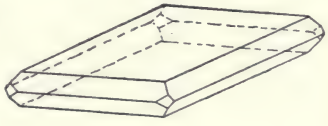


FIG. 532.

FIG. 533.—Celestite (Tabular). Woolmith Quarry, Monroe County, Michigan.

## CELESTITE, $SrSO_4$.

Orthorhombic, bipyramidal class. Tabular or prismatic crystals are common (Figs. 531, 532, and 533). Also in cleavable, granular, or fibrous masses.

Perfect basal and prismatic cleavages. Uneven fracture. Hardness 3 to 3.5. Specific gravity 3.9 to 4. Vitreous to pearly luster. Generally

possesses a faint blue tinge, but may be white, yellow, and more rarely green or reddish. Transparent to translucent.

$SrSO_4$. Usually very pure, but may contain small amounts of calcium and barium. Imparts a red color to the flame. More soluble in water than barite.

Celestite is usually associated with sulphur, gypsum, halite, aragonite, and occasionally galena and sphalerite. There are two principal types of occurrences:

(1) *Disseminated* as crystals or irregular particles in shales, limestones, and dolomites. By the action of circulating water the celestite is dissolved and these rocks become more or less porous. They are often called *gashed, acicular,* or *vermicular* limestones and dolomites. Such rocks occur near Syracuse, N. Y., and at various places in Michigan and northern Ohio.

(2) *In cracks* and *cavities* in rocks of varying ages but principally of sedimentary origin. Most of the best known localities for the occurrence of celestite are of this type. It is found in association with sulphur, gypsum, and aragonite in the Girgenti sulphur district of Sicily; also at Maybee, Michigan; with halite at Bex, Switzerland; excellent crystals, some over 18 inches in length are found on the Island of Put-in-Bay, Lake Erie; Mineral County, West Virginia; Kingston, Canada; San Bernardino County, California; Burnet County, Texas; Brown County, Kansas.

Used in the manufacture of strontium compounds.

**BARITE** (*Heavy Spar, Barytes*), $BaSO_4$.

Orthorhombic, bipyramidal class. Tabular and prismatic crystals are very common, usually well developed (Figs. 534 to 539); often com-

Fig. 534.

Fig. 535.

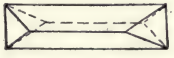


Fig. 536.

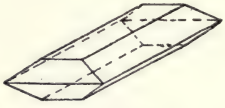


Fig. 537.

plex. Tabular crystals may be arranged in crested divergent groups (Fig. 540). Also in cleavable, granular, fibrous, or reniform masses; sometimes lamellar, nodular, or earthy.

Perfect basal and prismatic cleavages. Uneven fracture. Hardness 2.5 to 3.5. Specific gravity 4.3 to 4.7. Colorless, white, yellow, blue, brown, or red. Transparent to opaque. Vitreous to pearly luster.

$BaSO_4$. May contain varying amounts of the oxides of strontium and calcium; also silica, clay, or organic matter. Colors the flame green.

Barite is a common and widely distributed mineral. It occurs in metalliferous veins associated with galena, sphalerite, fluorite, chalcopyrite, and the various manganese and iron minerals. This type of occurrence furnishes most of the finest crystals of barite. Thus, Cornwall, Cumberland, and Derbyshire, England; Kapnik, Transylvania; Herren-

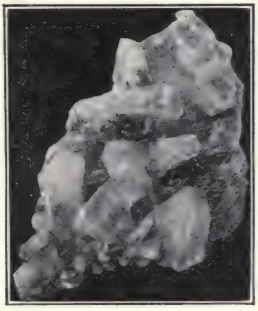


FIG. 538.—Barite (light) with stibnite. Transylvania.

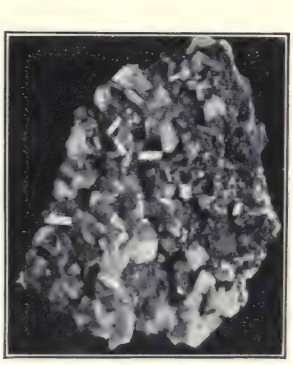


FIG. 539.—Barite. Schemnitz, Hungary.

grund, Hungary; Bohemia; Marquette County, Michigan; DeKalb, New York; Fort Wallace, New Mexico. Also in pockets and lenticular deposits in limestones, and associated with calcite and celestite. Deposits of this character are mined in Georgia, Missouri, Tennessee, Kentucky, Virginia, and North and South Carolina.

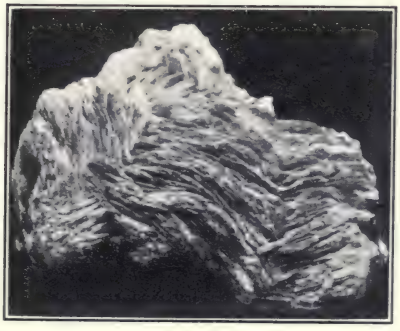


FIG. 540.—Barite (crested). Marquette County, Michigan.

Barite is used in large quantities in the manufacture of "ready mixed" paint, lithopone, wall paper, glass, artificial ivory, and insecticides. It is the principal source of the various barium compounds. Some varieties are used for ornamental purposes.

**ANGLESITE, $PbSO_4$.**

Orthorhombic, bipyramidal class. Crystals are frequently highly modified, and may be prismatic (Fig. 541), tabular, or pyramidal in habit. Massive varieties are compact, granular, or nodular.

Distinct basal and prismatic cleavages. Conchoidal fracture. Hardness 3. Specific gravity 6.1 to 6.4. Colorless, white, yellow, brown, green, or blue. Adamantine to greasy luster. Transparent to opaque.

$PbSO_4$. Usually quite pure. Fuses easily in a candle flame. Occurs as a pseudomorph after galena. Alters to cerussite.

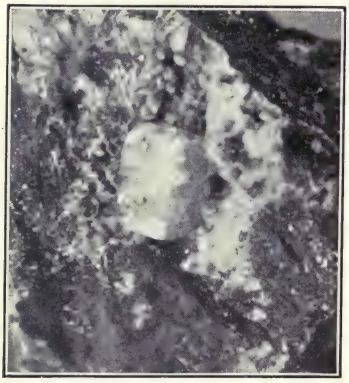


FIG. 541.—Anglesite (prismatic) in galena. Tintic District, Utah.

FIG. 542.—Crocoite. Near Dundas, Tasmania.

Anglesite is a common oxidation product of lead minerals, especially galena. It is commonly found in cracks and cavities with galena and cerussite. Other associates are sphalerite, smithsonite, hemimorphite, and limonite. Excellent crystals are found at Monte Poni, Sardinia; Clausthal, Germany; Anglesea, England; Leadhills, Scotland; Phoenixville, Pennsylvania; Tintic district, Utah; various places in Colorado, Missouri, Wisconsin, Arizona, and California; in large deposits in Mexico and Australia.

Anglesite is an ore of lead.

**Crocoite, $PbCrO_4$.**

Monoclinic, prismatic class. Commonly in prismatic or acicular crystals, often highly modified and striated (Fig. 542). Also columnar, granular, or in crusts.

Distinct basal and prismatic cleavages. Conchoidal to uneven fracture. Hardness 2.5 to 3. Specific gravity 5.9. to 6.1. Various shades of red, resembling potassium bichromate in color, Orange yellow streak. Adamantine luster to greasy. Translucent.

$PbCrO_4$. Usually quite pure.

An alteration product of galena and is usually associated with galena, quartz, pyrite, vanadinite, wulfenite, and limonite. Found in excellent crystals near Dundas, Tasmania; Siberia; Maricopa County, Arizona.

Not a common mineral and of no commercial importance.

## Wolframite Group

The members of this group crystallize in the tetragonal and monoclinic series, see page 254. The various tungstates are at present of great commercial importance.

### Wulfenite, $PbMoO_4$.

Tetragonal, tetragonal pyramidal class. Usually in square and thin tabular crystals (Fig. 543). Also pyramidal or short columnar. Sometimes with third order forms. Hemimorphic development very rare. Also in coarse to fine granular masses.

Hardness 3. Specific gravity 6.3 to 7. Resinous to adamantine luster. Various shades of yellow, red, or green; also gray or white. Yellowish white streak. Transparent to translucent.

Fig. 543.—Wulfenite. Bleiberg, Austria.

$PbMoO_4$. May contain some calcium, vanadium, molybdenum, or chromium. Occurs as a pseudomorph after galena.

Wulfenite is a secondary mineral, usually the result of the decomposition of lead minerals. It is commonly associated with galena, pyromorphite, and vanadinite. Occurs in Hungary; Saxony; Phoenixville, Pennsylvania; various places in Yuma, Maricopa, and Pinal Counties, Arizona; Searchlight, Nevada; also in Southampton, Massachusetts; Wisconsin, New Mexico, and California.

A source of molybdenum and its compounds. See page 205.

Fig. 544.

Fig. 545.—Scheelite on quartz. Zinnwald, Bohemia.

### Scheelite, $CaWO_4$.

Tetragonal, tetragonal bipyramidal class. Crystals are generally small and pyramidal in habit (Figs. 544 and 545); rarely tabular; some-

times with third order forms. More often as crystalline crusts on quartz, or in reniform, disseminated, or granular masses.

Distinct pyramidal cleavage. Conchoidal to uneven fracture. Hardness 4.5 to 5. Specific gravity 5.9 to 6.2. White, yellow, brown, green, or reddish. Adamantine to greasy luster. Transparent to opaque.

$CaWO_4$. Usually contains some molybednum. Occurs as a pseudomorph after wolframite.

Usually found with quartz, cassiterite, fluorite, topaz, molybdenite, wolframite, and apatite. Occurs in Cornwall and Cumberland, England; Schaggenwald and Zinnwald, Bohemia; New South Wales; New Zealand; Tasmania; Monroe and Trumbull, Connecticut; San Bernardino and Kern counties, California; Cochise, Pinal, and Santa Cruz counties, Arizona; Jardine, Montana; White Pine and Humboldt counties, Nevada.

An important source of tungsten and its compounds.

**Huebnerite, $MnWO_4$.**

Monoclinic, prismatic class. Generally in long fibrous, bladed, (Fig. 546), or stalky crystals without good terminations. Also in compact, lamellar,or cleavable masses.

Clinopin coidal cleavage. Hardness 4.5 to 5.5. Specific gravity 6.7 to 7.3. Brownish, red, brownish black, pale yellow, or nearly black in color, in transmitted light, pale ruby red to yellow. Submetallic to resinous luster. Translucent to opaque. Streak-yellow to yellow-brown.

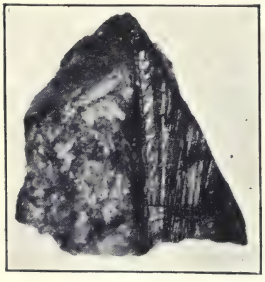


FIG. 546.—Huebernite in quartz. Pima County, Arizona.

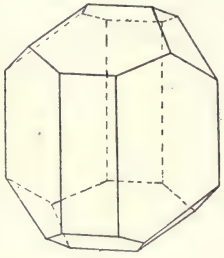


FIG. 547.

FIG. 548.—Wolframite. Trumbull, Connecticut.

Huebnerite, $MnWO_4$. Usually contains iron and passes over into wolframite, see page 261.

Occurs in quartz veins with wolframite, fluorite, pyrite, scheelite, galena, tetrahedrite, and muscovite. Thus, in Lemhi County, Idaho; White Pine County, Nevada; Ouray, and San Juan counties, Colorado.

An important source of tungsten and its compounds.

**WOLFRAMITE, $(Fe,Mn)WO_4$.**

Monoclinic, prismatic class. Crystals are thick tabular or short columnar, and often quite large (Figs. 547 and 548). Commonly in bladed, curved lamellar, or granular masses.

Perfect clinopinacoidal cleavage. Uneven fracture. Hardness 5 to 5.5. Specific gravity 7.1 to 7.5. Dark gray, reddish brown, brownish black, or iron black in color. Streak varies from dark red brown for manganiferous varieties to black for those containing much iron. Greasy submetallic luster. Opaque. Sometimes slightly magnetic.

$(Fe,Mn)WO_4$. An isomorphous mixture of $MnWO_4$ and $FeWO_4$ in which the composition of one of these constituents is not less than 20 per cent. and the other not over 80 per cent. Wolframite is therefore intermediate between huebnerite and ferberite. Occurs as a pseudomorph after scheelite.

Occurs with quartz, mica, fluorite, cassiterite, apatite, scheelite, molybdenite, huebnerite, ferberite, galena, and sphalerite. Some localities are: Cornwall, England; various places in Saxony; Zinnwald, Bohemia; Siberia; New South Wales; Burma; Malay States; Portugal; Black Hills, South Dakota; Monroe and Trumbull, Connecticut. Boulder County, Colorado, is the chief producing locality in the United States.

Wolframite is a source of tungsten and its compounds. Tungsten is used in the manufacture of "high speed" tool steels and as the filament in electric incandescent lamps; sodium tungstate as a mordant and to render cloth inflammable; tungstic oxide to color glass; and calcium tungstate in X-ray apparatus.

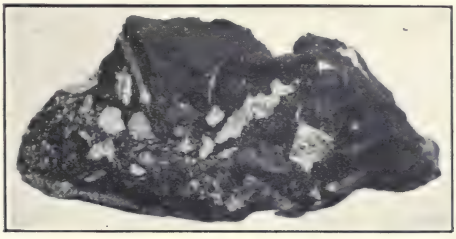


FIG. 549.—Ferberite. Boulder County, Colorado.

**Ferberite, $FeWO_4$.**

Monoclinic, prismatic class. Crystals are usually tabular and in crested aggregates. Also in compact and granular masses (Fig. 549).

Perfect clinopinacoidal cleavage. Uneven fracture. Hardness 5. Specific gravity 7.5. Brown to black in color and streak. Opaque.

$FeWO_4$. Usually contains manganese and passes over into wolframite, see above.

Occurs with quartz, hematite, limonite, molybdenite, pyrite, scheelite

wolframite, and sylvanite. The principal occurrences are in Boulder County, Colorado.

Uses are the same as for wolframite.

---

**Uraninite,** (*Pitchblende*), $UO_3$, $UO_2$, PbO, etc.

Cubic, hexoctahedral class. Crystals generally show the octahedron and rhombic dodecahedron, but are rare. Commonly in compact, botryoidal, reniform, curved lamellar, or granular masses. Often apparenty amorphous (Fig. 550).

Conchoidal to uneven fracture. Hardness 3 to 6. Specific gravity 4.8 to 9.7, crystals 9 to 9.7. Pitchy to submetallic luster on fresh fracture surfaces, otherwise dull. Brown to black in color. Dark green, brown, or black streak. Non-magnetic.

Composition is uncertain. Is considered an uranate of uranyl and lead with varying percentages of the rare earths thorium, cerium, yttrium lanthanum, and erbium, and the gases nitrogen, argon, and helium. May also contain radium and be strongly radio-active. This element was discovered in uraninite from Joachimsthal, Bohemia. *Cleveite* is a variety from near Arendal, Norway, and contains thorium, argon, and helium. *Nivenite* is characterized by about 10 per cent. of the earths of the yttrium groups. It occurs in Llano County, Texas. *Bröggerite* occurs on the Island of Moss, near Christiania, Sweden, and contains considerable thorium.

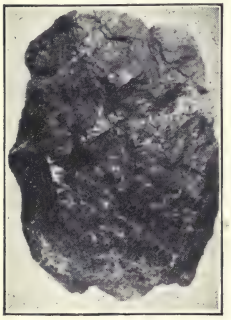


Fig. 550.—Uraninite or pitchblende. Joachimsthal, Bohemia.

As a primary constituent of pegmatites and granites, associated with orthite, thorite, and fergusonite, it is found in the Arendal and Moss districts, Norway; Sweden; Branchville, Connecticut; Mitchell County, North Carolina; Llano County, Texas; Black Hills, South Dakota. With lead, silver, bismuth, and tin minerals it occurs at Joachimsthal and Pribram, Bohemia; Johanngeorgenstadt, Saxony; Cornwall, England; Gilpin County, Colorado.

Uraninite is an important source of uranium and radium compounds. Uranium is used in the manufacture of special grades of steels; its compounds for coloring glass and as pigments for porcelain painting. As is well known, radium compounds possess important chemical, physical, and medicinal properties.

**ALUNITE** (*Alum Stone*), $K_2(Al.2OH)_6(SO_4)_4$.

Hexagonal, ditrigonal scalenohedral class. Crystals are generally small rhombohedrons resembling cubes, often with curved surfaces; more rarely tabular. Commonly compact, granular, fibrous, or earthy (Fig. 551).

Perfect basal cleavage. Conchoidal, splintery, or earthy fracture. Hardness 3.5 to 4, sometimes harder due to admixtures of quartz and feldspar. Tough. Specific gravity 2.58 to 2.8. Colorless, white, yellowish, or reddish. Pearly luster on cleavage surfaces, otherwise vitreous. Transparent to translucent.

$K_2(Al.2OH)_6(SO_4)_4$ May contain some sodium. Insoluble in hydrochloric acid and water.

Alunite occurs in irregular deposits and in veins in altered feldspathic rocks, such as rhyolites, trachytes, and andesites. Common associates are kaolin, pyrite, opal, and quartz. Occurs in Hungary, Greece, France, Mexico, and Japan. In the United States it is found at Silverton and Cripple Creek, Colorado; Mariposa County, California; Morenci, Arizona; in large quantities with gold in the Goldfield district, Nevada, and Marysvale, Utah.

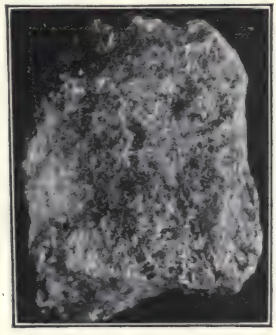


FIG. 551.—Alunite. Talfa, Italy.

FIG. 552.—Brochantite. Chuquicamata, Chile.

Alunite is a source of alum and potassium sulphate, which is obtained by roasting and subsequent leaching. Some of the Hungarian varieties are so hard and tough as to be used for millstones.

**Bronchantite, $CuSO_4.3Cu(OH)_2$.**

Orthorhombic, bipyramidal class. Short prismatic and acicular crystals with vertical striations. Also reniform with fibrous structure, and as drusy crusts (Fig. 552).

Perfect brachypinacoidal cleavage. Hardness 3.5 to 4. Specific gravity 3.8 to 3.9. Emerald to blackish green in color. Light green streak. Transparent to translucent. Vitreous to pearly luster.

$CuSO_4.3Cu(OH)_2$. Loses water at 300°C.

A secondary copper mineral, commonly associated with malachite, azurite, cuprite, chalcopyrite, and limonite. Occurs in Hungary; Ural Mountains; Bolivia; Chile; Sonora, Mexico; in various copper districts; Arizona; Chaffee County, Colorado; Tintic district, Utah.

Of minor importance as a copper mineral.

**GYPSUM,** *Selenite, Satin Spar, Alabaster,* **$CaSO_4.2H_2O$.**

Monoclinic, prismatic class. Crystals are usually simple and either tabular or prismatic in habit. Sometimes twinned parallel to the ortho-

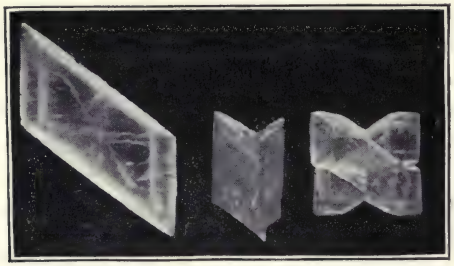


FIG. 553.—Gypsum crystals—tabular, contact and penetration twins.

FIG. 554.

FIG. 555.

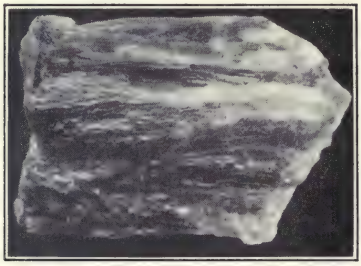


FIG. 556.—Gypsum (columnar or "pencil rock"). Grand Rapids, Michigan.

FIG. 557.—Gypsum: Variety, satin spar. Montmartre, Paris, France.

pinacoid, yielding contact (swallow-tail) and penetration twins (Figs. 553, 554 and 555). Very common in cleavable, columnar (Fig. 556), granular, fibrous, foliated, or earthy masses.

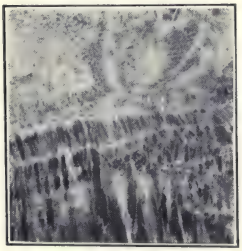


FIG. 558.—Gypsum (polished). Grand Rapids, Michigan.

There are three cleavages parallel to (1) clinopinacoid, (2) positive unit hemi-pyramid, and (3) orthopinacoid, yielding very thin and smooth folia, and fibrous and conchoidal surfaces, respectively. Hardness 2. Specific gravity 2.2 to 2.4. Vitreous to pearly or silky luster. Colorless, white, gray, yellow, brown, reddish, or black. Transparent to opaque.

$CaSO_4.2H_2O$. Often mixed with clay, sand, or organic matter. Yields water when heated and becomes white and opaque. Soluble in 380 to 460 parts of water.

There are five varieties of gypsum.

(1) *Selenite.*—This includes crystals and cleavable masses, and is usually colorless and transparent.

(2) *Satin Spar.*—A fibrous variety often with a pronounced silky luster (Fig. 557). Sometimes used in cheap jewelry.

(3) *Alabaster.*—A massive usually fine grained variety (Fig. 558). Sometimes used for statuary purposes.

(4) *Rock Gypsum.*—A compact scaly or granular variety, often very impure. It is frequently ground and used as a fertilizer under the name of *landplaster.*

(5) *Gypsite.*—An impure, earthy or sandy variety occurring abundantly in Kansas, Arizona, New Mexico, and Oklahoma.

Gypsum is a common mineral and often occurs in extensive deposits of great thickness. It is usually found with limestones and shales, and in connection with salt deposits. Deposits of this character are frequently of great commercial importance. Some of the best known and most extensively worked occurrences are in central and western New York; Alabaster and Grand Rapids, Michigan; Fort Dodge, Iowa; Blue Rapids, Gypsum City, and Medicine Lodge, Kansas; also various places in Oklahoma, Texas, Oregon, South Dakota, and Wyoming. Large deposits occur also at Hillsboro, Albert County, New Brunswick; and in Nova Scotia. Excellent transparent crystals are found at Ellsworth and Canfield in Trumbull County, and also in Mahoning County, Ohio; very large crystals in Wayne County, Utah. New York, Michigan, and Iowa are the chief producers of gypsum.

Although most gypsum is the result of deposition from solution, it is sometimes formed by the hydration of anhydrite, in volcanic regions, by the action of sulphurous vapors upon limestone, and in metalliferous veins by the action of sulphuric acid resulting from the oxidation of metallic sulphides. The common associates are halite, celestite, sulphur, aragonite, dolomite, calcite, pyrite, and quartz.

Ground rock gypsum is used as a fertilizer and is called *land plaster.* It is also used as a disinfectant, flux in glass and porcelain manufacture, retarder in cement, and to weight fertilizers. Alabaster is used for statuary and decorative purposes. Satin spar and a small amount of selenite are used in cheap jewelry and microscopy, respectively. It is also used as an adulterant of foods, medicines, and paints. When gypsum is calcined so as to drive off $1\frac{1}{2}$ molecules of water, it forms *plaster of Paris,* which has the property of *setting* or becoming hard after being mixed with water. Plaster of paris is used in very large quantities in patent wall plasters, stucco, white wash, dentistry, crayons, casts, and in many other ways.

**Epsomite** (*Epsom Salt*), $MgSO_4.7H_2O$.

Orthorhombic, bisphenoidal class. Occasionally in nearly square prismatic crystals (Fig. 559). Commonly as granular, fibrous, or earthy masses, or in crusts.

Perfect brachypinacoidal cleavage. Hardness 2 to 2.5. Specific

gravity 1.7 to 1.8. Colorless or white. Transparent to translucent. Bitter salty taste.

$MgSO_4.7H_2O$. Soluble in water. Non-hygroscopic.

Epsomite is a common constituent of ocean, salt lake, and spring waters. Thus, it occurs in the springs at Epsom, England; Seidlitz and elsewhere, Bohemia; Ofen, Hungary. As an alteration product of kieserite, it is found in the salt deposits of Stassfurt, Germany. It may be the result of the action of sulphuric acid from decomposing sulphides on serpentine, talc, magnesite, or other magnesium rocks. At Montmartre, near Paris, it occurs with gypsum. It is also found in limestone caves in Kentucky, Tennessee, and Indiana, and in crusts on the alkali plains of Utah, Nevada, and California. With mirabilite it occurs in Albany County, Wyoming.

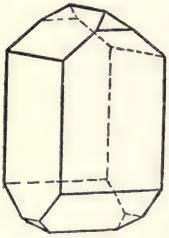


Fig. 559.

Epsomite is used in medicine, as a fertilizer in place of gypsum, and as a coating for cotton cloth.

**Melanterite** (*Copperas*), $FeSO_4.7H_2O$.

Monoclinic, prismatic class. Crystals are very rare. Usually as earthy, fibrous or capillary crusts or efflorescences.

Conchoidal to earthy fracture. Hardness 2. Specific gravity 1.8 to 1.9. Various shades of green in color, often yellowish after exposure. Vitreous to dull luster. Transparent to translucent. Sweet, astringent taste, somewhat metallic.

$FeSO_4.7H_2O$. Sometimes contains manganese, magnesium, copper, or zinc. Easily soluble in water. Loses water on exposure and crumbles to powder.

Decomposition product of iron sulphide minerals, especially pyrite, marcasite, chalcopyrite, and pyrrhotite. Some localities are: Hartz Mountains; Bodenmais, Bavaria; Falun, Sweden; Rio Tinto, Spain. In the United States, it is generally found as an efflorescence with the sulphides of iron.

Melanterite does not occur abundantly enough in nature to be of commercial importance. The artificial compound is used in large quantities as a mordant in dyeing, as a disinfectant, and in the manufacture of inks, blueing, and pigments.

**Chalcanthite** (*Blue Vitriol, Blue Stone*), $CuSO_4.5H_2O$.

Triclinic, pinacoidal class. Rarely as small, flat crystals. Generally in crusts with reniform, stalactitic, or fibrous structure.

Crystals possess imperfect basal and prismatic cleavages. Conchoidal fracture. Hardness 2.5. Specific gravity 2.1 to 2.3. Vitreous to dull luster. Deep blue, sky blue, or greenish blue in color. White to light blue streak. Translucent. Disagreeable metallic taste.

$CuSO_4.5H_2O$. May contain iron. Readily soluble in water yielding a blue solution, especially when ammoniacal.

Chalcanthite is an alteration product of copper minerals, such as chalcopyrite, chalcocite, and bornite. Occurs in the mines of the Hartz Mountains; also in Hungary; Falun, Sweden; Rio Tinto, Spain; Chessy, France; and Cornwall, England; Wicklow, Ireland. It was formerly found in considerable quantities in the Bluestone mine, near Reno, Nevada, and at Copiapo, Chile. Found also in the waters of the copper mines of Arizona and Montana. The copper in such mine water is recovered by precipitation with scrap iron.

Only rarely does it occur in sufficient quantities to be of commercial importance. The artificial compound is used in copper-plating, in batteries, as a mordant and preservative of timber, and for spraying plants.

### 7. ALUMINATES, FERRITES, AND BORATES

Of the six minerals described in this division, five have analogous chemical compositions and are considered as forming an isodimorphous series.

| | | |
|---|---|---|
| | SPINEL GROUP | |
| **SPINEL** | $Mg(AlO_2)_2$ | Cubic |
| **MAGNETITE** | $Fe(FeO_2)_2$ | Cubic |
| **FRANKLINITE** | $(Fe,Mn,Zn)(FeO_2)_2$ | Cubic |
| **CHROMITE** | $(Fe,Cr)[(Cr,Fe)O_2]_2$ | Cubic |
| **Chrysoberyl** | $Be(AlO_2)_2$ | Orthorhombic |
| **Colemanite** | $Ca_2B_6O_{11}.5H_2O$ | Monoclinic |

Colemanite is the only borate occurring in nature in sufficient quantities to be of any commercial importance.

#### Spinel Group

Several members of this group rank among the very important minerals. All these minerals are hard, 5.5 to 8.5; those with metallic luster are the softer, varying from 5.5 to 6.5.

**SPINEL, $Mg(AlO_2)_2$.**

Cubic, hexoctahedral class. Octahedral crystals (Fig. 560), frequently in combination with the rhombic dodecahedron (Fig. 561) Contact twins are common, twinned parallel to a face of the octahedron (Spinel law). Generally in disseminated or loose crystals, or in rounded grains.

Imperfect octahedral cleavage. Hardness 7.5 to 8. Specific gravity 3.5 to 4.5. Vitreous to nearly dull in luster. All colors, but chiefly red, blue, green, brown, and black. Transparent to opaque.

$Mg(AlO_2)_2$. Magnesium may be replaced by iron, zinc, or manganese; the aluminum by ferric iron and chromium. Infusible.

There are several important varieties:

1. *Ruby Spinel.*—Deep red in color, transparent.
2. *Rubicelle.*—Yellow or orange red in color.
3. *Blue Spinel.*—Light blue in color.
4. *Pleonaste.*—An iron-magnesium spinel. Dark green, brown, or black. Usually opaque or nearly so.
5. *Picotite.*—Contains chromium. Black, yellow, or greenish brown. Translucent to nearly opaque.
6. *Gahnite.*—Contains considerable zinc. Commonly in fairly large crystals. Various shades of green, also brown or black. Translucent to opaque.

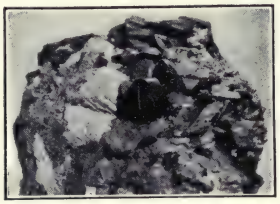


FIG. 560.—Spinel (octahedron). Labelle County, Quebec, Canada.

FIG. 561.—Spinel (octahedron and rhombic dodecahedron) in calcite. Franklin Furnace, New Jersey.

Spinel is a common metamorphic mineral occurring usually in granular limestones, gneiss, and serpentine. It is also an accessory constituent of basic igenous rocks. Gem spinels are frequently found in placer deposits, especially in Ceylon, Burma, and Siam. The common associates are calcite, chondrodite, corundum, graphite, and olivine. Important localities are: Aker, Sweden; Orange and St. Lawrence counties, New York; Franklin Furnace, New Jersey; Bolton, Massachusetts; Macon County, North Carolina.

Transparent red and blue varieties are highly prized as gems.

**MAGNETITE** (*Magnetic Iron Ore, Lodestone*), $\mathbf{Fe(FeO_2)_2}$.

Cubic, hexoctahedral class. Octahedral and rhombic dodecahedral crystals are very common, often very perfect and with bright surfaces. Striated faces are, however, not infrequently observed. Twinned according to the spinel law, yielding contact and polysynthetic twins. Crystals are sometimes highly modified and may be greatly distorted (Fig. 562). Usually occurs in coarse to fine grained masses, in lamellar to compact aggregates, as disseminated grains, or as loose grains or sand; more rarely dendritic, especially in mica.

Octahedral parting. Conchoidal to uneven fracture. Hardness 5.5 to 6.5. Specific gravity 4.9 to 5.2. Metallic, submetallic, to dull luster. Iron black color. Black streak. Opaque. Strongly magnetic (Fig. 563).

$Fe(FeO_2)_2$. Commonly written $Fe_3O_4$. May contain magnesium,

nickel, manganese, phosphorus, or titanium. Fuses with difficulty. Alters to limonite and hematite (martite). Magnetite occurs as a pseudomorph after pyrite, hematite, and siderite.

Magnetite occurs rather widespread, being found principally as (1) a primary constituent of basic igneous rocks, such diabase, gabbro, nepheline syenite, and basalt; (2) as a metamorphic mineral; and (3)

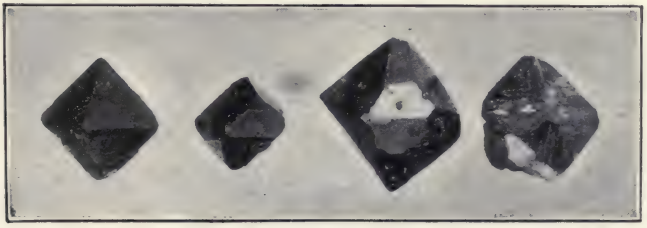


FIG. 562.—Magnetite crystals—octahedron, rhombic dodecahedron, tetragonal trisoctahedron, striated.

as a constituent of certain river, lake, and sea sands, called *black sands*. The common associates are chlorite (Fig. 564), hornblende, pyroxene, feldspar, quartz, pyrite, chalcopyrite, epidote, chromite, garnet, and ilmenite. Large deposits are found in Norway and Sweden; Ural Mountains; Brazil; Mineville, New York; Cornwall, Pennsylvania; Oxford,

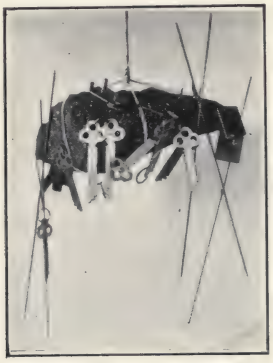


FIG. 563.—Magnetite: Variety, lodestone. Magnet Cove, Arkansas.

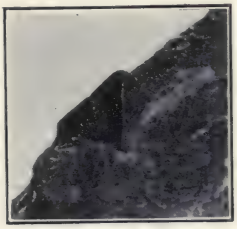


FIG. 564.—Magnetite (octahedron) in chloritic schist. Zillerthal, Tyrol.

New Jersey. Black sands are rather widespread in Alaska, California, Idaho, Montana, Colorado, Oregon, and Washington. They sometimes carry small amounts of platinum. Magnetite from Magnet Cove, Arkansas, is usually very strongly magnetic, and is termed *lodestone*.

Magnetite is an important iron ore. About 5 per cent. of all the iron ore mined annually in the United States is magnetite.

**FRANKLINITE** (**Fe, Mn, Zn**) $(FeO_2)_2$.

Cubic, hexoctahedral class. The octahedron is rather common, sometimes with the rhombic dodecahedron (Fig. 565) and with rounded edges. Occurs usually in compact and granular masses, or as rounded grains.

Imperfect octahedral cleavage. Conchoidal fracture. Hardness 5.5. to 6.5. Specific gravity 5 to 5.2. Metallic or dull luster. Iron black in color. Brown, reddish, or black streak. Often slightly magnetic. Opaque.

$(Fe,Mn,Zn)(FeO_2)_2$. The composition varies greatly, ZnO from 17 to 25 per cent., MnO 10 to 12 per cent., and $Fe_2O_3$ about 60 per cent. When heated becomes strongly magnetic. Infusible.

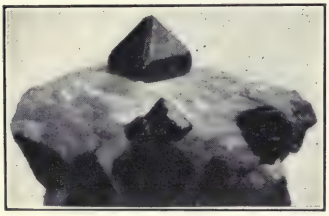


FIG. 565.—Franklinite (octahedron and rhombic dodecahedron) with calcite. Franklin Furnace, New Jersey.

Franklinite occurs extensively in the metamorphic area about Franklin Furnace and Sterling Hill, Sussex County, New Jersey, where it is associated with willemite, zincite, rhodonite, and calcite. Also found in cubical crystals at Eibach, Germany.

Franklinite is a source of zinc which, by heating the mineral, is easily obtained either as spelter or zinc oxide. The residue contains about 12 per cent. of manganese and 40 per cent. iron, and is used as spiegeleisen in the manufacture of steel.

**CHROMITE** (*Chrome Iron, Chromic Iron Ore*), (**Fe,Cr**) $[(Cr,Fe)O_2]_2$.

Cubic, hexoctahedral class. Rarely in octahedral crystals. Usually in fine granular, compact masses, or as disseminated grains.

Indistinct octahedral cleavage. Uneven to conchoidal fracture. Hardness 5.5. Specific gravity 4.3 to 4.6. Pitchy submetallic to metallic luster. Opaque. Iron black to brownish black in color. Dark brown to grayish streak. Sometimes slightly magnetic.

$(Fe,Cr)[(Cr,Fe)O_2]_2$. May contain magnesium and aluminum.

Chromite occurs usually in veins and irregular masses in basic magnesium rocks, especially serpentine. It is often the result of magmatic segregation. The common associates are serpentine, talc, chrome garnet, zaratite, and corundum. It occurs at Franckenstein, Silesia; New Zealand; Rhodesia; New Caledonia; Asiatic Turkey; Texas; Lancaster County, and elsewhere in Pennsylvania; Baltimore County, Maryland; Shasta and other counties in California; also in North Carolina, Oregon, Washington, and Wyoming. Also found in platinum placers and in black sands.

Chromite is used in the manufacture of refractory chrome bricks and furnace linings; for making special grades of steels, such as ferro-

chrome used for cutting tools, projectiles, and armor plate; also for the production of pigments, dyes, and mordants, and in tanning.

**Chrysoberyl, $Be(AlO_2)_2$.**

Orthorhombic, bipyramidal class. Crystals are tabular, also heart-shaped and pseudohexagonal twins; frequently striated (Figs. 566, 567 and 568). Also as crystal fragments, and loose or rounded grains.

Distinct brachypinacoidal cleavage. Conchoidal fracture. Hardness 8.5. Specific gravity 3.5 to 3.8. Vitreous to greasy luster. Greenish white, greenish yellow, and asparagus to emerald green in color; often red in transmitted light. Transparent to translucent. Some varieties have a bluish opalescence or chatoyancy.

FIG. 566.

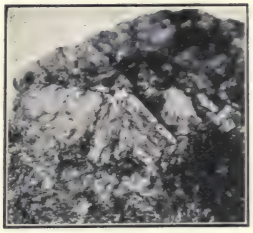


FIG. 567.—Chrysoberyl (twin). Haddam, Connecticut.

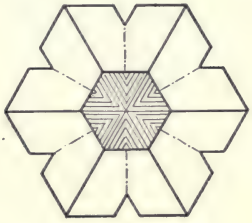


FIG. 568.

$Be(AlO_2)_2$. May contain some iron and chromium. Infusible. Insoluble in acids.

There are three varieties:

(1) *Ordinary Chrysoberyl.* Usually green or pale green in color.

(2) *Alexandrite.* Emerald green in color, but red in transmitted gas or lamp light; with tungsten light, intermediate between red and green.

(3) *Cat's Eye or Cymophane.* An opalescent, yellow green variety.

Chrysoberyl is usually found in gneiss, mica schist, or granite. Common associates are beryl, tourmaline, garnet, apatite, and sillimanite. It occurs in the Ural Mountains; Haddam, Connecticut; Norway and Stoneham, Maine; Greenfield, New York; as rounded pebbles in the gem placers of Ceylon, Tasmania, and Brazil.

Transparent varieties are highly prized as gems.

---

**Colemanite, $Ca_2B_6O_{11}.5H_2O$.**

Monoclinic, prismatic class. Crystals are usually short prismatic and resemble datolite (Fig. 569); often highly modified. Also in compact, granular, and cleavable masses, which resemble chalk or porcelain.

Highly perfect clinopinacoidal cleavage. Uneven to subconchoidal fracture. Hardness 3.5 to 4.5. Specific gravity 2.4. Vitreous to dull luster. Colorless to white. Transparent to opaque.

$Ca_2B_6O_{11}.5H_2O$. Easily soluble in hot hydrochloric acid. Boracic

acid separates on cooling. Insoluble in water. Treated with sodium carbonate or sulphate it yields borax, $Na_2B_4O_7.10H_2O$.

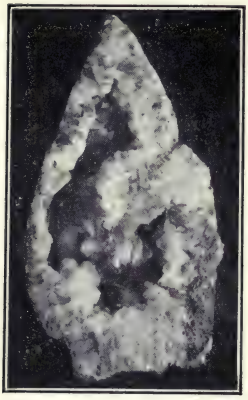


FIG. 569.—Colemanite (geode). San Bernardino County, California.

Commonly associated with halite, thenardite, trona, gypsum, celestite, and quartz. As a lake deposit it occurs extensively in San Bernardino, Inyo, Los Angeles, and Ventura counties, California.

Colemanite is the chief source of borax, which is used extensively in the manufacture of soap, enamels, glass, washing powders, ointments, and lotions; also in welding, soldering, assaying, and blowpiping, as an antiseptic, and in the preservation of meat and fish.

## 8. PHOSPHATES, COLUMBATES, AND VANADATES

A large number of minerals belonging to this division have been recorded in the literature, but only seven are of sufficient importance to warrant a description.

| | | |
|---|---|---|
| **Monazite** | $(Ce,La,Di)PO_4$ | Monoclinic |
| **COLUMBITE** | $(Fe,Mn)[(Cb,Ta)O_3]_2$ | Orthorhombic |
| | APATITE GROUP | |
| **APATITE** | $Ca_5F(PO_4)_3$ | Hexagonal |
| **PYROMORPHITE** | $Pb_5Cl(PO_4)_3$ | Hexagonal |
| **Vanadinite** | $Pb_5Cl(VO_4)_3$ | Hexagonal |
| **Wavellite** | $(Al.OH)_3(PO_4)_2.5H_2O$ | Orthorhombic |
| **Turquois** | $H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$ | Triclinic |
| **Carnotite** | $K_2O.2UO_3.V_2O_5.3H_2O$ | Orthorhombic |

Columbite is a salt of metatantalic acid, $H_2TaO_3$. The phosphates can be referred to the orthophosphoric acid, $H_3PO_4$, while vanadinite is a derivative of a corresponding acid, $H_3VO_4$.

**Monazite, $(Ce,La,Di)PO_4$.**

Monoclinic, prismatic class. Crystals are thick tabular or square prismatic, usually small and not common. Generally found as angular disseminated masses and rolled grains in sand.

Perfect basal cleavage. Conchoidal fracture. Hardness 5 to 5.5. Specific gravity 4.9 to 5.3. Brownish gray, yellow, or reddish in color. White streak. Resinous luster. Translucent to opaque.

$(Ce,La,Di)PO_4$. May contain from ½ to 20 per cent. of $ThO_2$. Commercial monazite sand contains usually from 2.5 to 5 per cent. $ThO_2$.

Occurs disseminated in granites and gneisses, thus, at Arendal,

Norway; Miask, Ural Mountains; Binnenthal, Switzerland; Amelia Court House, Virginia. The most important occurrence of monazite is as sand, extensive deposits of which are found in the western part of North and South Carolina and Georgia; in the provinces of Bahia, Minas Geræs, Rio de Janeiro, and Sao Paulo, Brazil; Travancore, India; also in the Ural Mountains. Common associates are magnetite, zircon, garnet, ilmenite, thorite, gold, chromite, and sometimes the diamond.

Monazite is the chief source of thorium dioxide which is used extensively in the manufacture of incandescent mantles. United States consumes about one-fourth of the thorium nitrate used in the world. Most of the world's supply is obtained from Brazil.

**COLUMBITE, $(Fe,Mn)[(Cb,Ta)O_3)]_2$.**

Orthorhombic, bipyramidal class. Short prismatic or thick tabular crystals, often resembling those of wolframite. Also massive and disseminated.

Brachypinacoidal cleavage. Conchoidal to uneven fracture, often with iridescent tarnish. Hardness 6. Specific gravity 5.4 to 6.4. Brown to iron black in color. Brownish, reddish, or black streak. Greasy, submetallic to dull luster.

$(Fe,Mn)[(Cb,Ta)O_3)]_2$. Composition varies greatly. Frequently containing tin and tungsten. When tantalum predominates it is called *tantalite*. Infusible. Not attacked by acids.

Columbite occurs in granite pegmatites, associated with beryl, tourmaline, spodumene, lepidolite, cryolite, quartz, feldspar, wolframite, and cassiterite. It occurs at Ivigtut, Western Greenland; Bodenmais, Bavaria; Miask, Ural Mountains; Western Australia; Standish, Maine; Branchville, Connecticut; Mitchell County, South Carolina; Black Hills, South Dakota; Amelia County, Virginia.

An important source of columbium and tantalum. Filaments of tantalum have been used in electric incandescent lamps.

### Apatite Group

This group contains the calcium and lead salts of orthophosphoric and orthovanadic acids. These minerals form an interesting isomorphous series.

**APATITE, $Ca_5F(PO_4)_3$.**

Hexagonal, hexagonal bipyramidal class. Prismatic and thick tabular crystals are common, often well developed and highly modified. Sometimes large. The edges may be rounded and have a fused appearance. At times forms of the third order are to be observed (Fig. 570). Also in compact, fibrous, nodular, reniform, oölitic, or earthy masses.

Imperfect basal cleavage. Conchoidal fracture. Hardness 5. Spe-

cific gravity 3.1 to 3.2. Sometimes colorless and transparent, but usually translucent to opaque and variously colored, brown, green, gray, yellow, red, or white. The color is often unevenly distributed. Vitreous to greasy luster.

Apatite is essentially an orthophosphate of calcium containing fluorine, chlorine, or hydroxyl in varying amounts. Hence, the following formulas have been assigned to it, $Ca_5F(PO_4)_3$, $Ca_5Cl(PO_4)_3$ and $Ca_5(Cl,F,OH)(PO_4)_3$. Fluorine usually predominates, *fluor-apatite* being more common than *chloro-apatite*. Magnesium, manganese, and iron may also be present. Fuses with difficulty. Easily soluble in acids. May phosphoresce when heated.

There are three important varieties:—

(1) *Ordinary Apatite.* This includes crystallized, cleavable, and granular varieties.

FIG. 570.—Apatite crystals—prismatic, fused edges and corners, tabular.

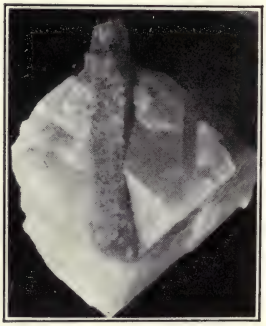


FIG. 571.—Apatite in calcite. Franklin Furnace, New Jersey.

(2) *Phosphate Rock.*—An impure massive variety containing 15 to 40 per cent. of $P_2O_5$ Color is gray, white, brown, or black. The hardness varies from 2 to 5. It occurs in beds, or as nodules and concretions.

(3) *Guano.*—Animal excrement, chiefly of birds, rich in phosphoric acid. Gray to brown in color, and porous, granular, or compact in structure.

Apatite is a common accessory constituent of many igneous rocks. It is an associate of metalliferous ore deposits, especially those of magnetite and cassiterite. It occurs also in granular limestones (Fig. 571), and in fact is present in small quantities in nearly all types of rocks. Common associates are calcite, cassiterite, quartz, fluorite, wolframite, and magnetite. Some important localities are: Ehrenfriedersdorf, Saxony; Schlaggenwald, Bohemia; St. Gothard, Switzerland; Knappenwand, Tyrol; Japan; Renfrew County, Ontario; Ottawa County, Quebec; Norwich and Bolton, Massachusetts; St. Lawrence and Jefferson counties, New York; Chester County, Pennsylvania; Franklin Furnace, New Jersey; Auburn, Maine.

Phosphate rock occurs in extensive deposits in Florida, South Carolina, Tennessee, Pennsylvania, Arkansas, Wyoming, Idaho, Utah, and Montana.

Phosphate rock is used in enormous quantities in the manufacture of fertilizers, its phosphoric acid content being rendered available by treating with sulphuric acid. Apatite is also used to some extent as a source of phosphorous.

**PYROMORPHITE, $Pb_5Cl(PO_4)_3$.**

Hexagonal, hexagonal bipyramidal class. Crystals are usually small, rounded, or barrel-shaped (Fig. 572). Often hollow and skeletal, or in parallel groups. Sometimes they resemble those of apatite. Occurs also in botryoidal and reniform aggregates, disseminated, and in crusts.

Conchoidal to uneven fracture. Hardness 3.5 to 4. Specific gravity 6.9 to 7.1. Usually some shade of green, but may be yellow, gray, brown, orange, or white. White to pale yellow streak. Greasy to adamantine luster. Translucent to opaque.

$Pb_5Cl(PO_4)_3$. May contain calcium, fluorine, or arsenic. Occurs as a pseudomorph after galena and cerussite.

Pyromorphite is generally a secondary mineral formed from the decomposition of lead ores. Common associates are galena, cerussite, barite, and limonite. It occurs in the Freiberg district, Saxony; Clausthal, Hartz Mountains; Ems, Nassau; Cornwall and Cumberland, England; Phoenixville, Pennsylvania; Lubec and Lenox, Maine; Lead hill, Scotland; Coeur d'Alene, Idaho.

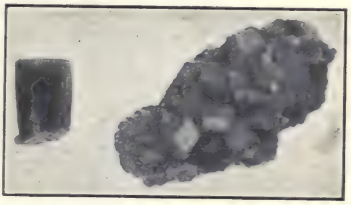


FIG. 572.—Pyromorphite. Ems, Nassau, Germany.

A minor source of lead.

**Vanadinite, $Pb_5Cl(VO_4)_3$.**

Hexagonal, hexagonal bipyramidal class. Crystals are usually prismatic, often skeletal and resembling those of pyromorphite. Occurs also compact, fibrous, globular, and in crusts.

Uneven to conchoidal fracture. Hardness 3. Specific gravity 6.7 to 7.2. Yellow, brown, or red in color. White to pale yellow streak. Translucent to opaque. Resinous luster.

$Pb_5Cl(VO_4)_3$. May contain phosphorous or arsenic. *Endlichite* is a light yellow variety containing arsenic. Fuses easily. Readily soluble in nitric acid.

Occurs associated with lead minerals, but never in large quantities. Some localities are: Zimapan, Mexico; Ural Mountains; various places in Yuma, Maricopa, Pinal, and Yavapai Counties, Arizona; Kelley, New Mexico.

It is a source of vanadium and its compounds.

**Wavellite $(Al.OH)_3(PO_4)_2.5H_2O$.**

Orthorhombic, bipyramidal class. Good crystals are very rare. Usually in crystalline crusts, or hemispherical or globular masses made up of concentric layers and possessing a radial fibrous structure (Fig. 573).

Conchoidal to uneven fracture. Hardness 3.5 to 4. Specific gravity 2.3 to 2.4. May be colorless, but is usually gray, yellow, green, blue, or black. Vitreous luster. Translucent.

$(Al.OH)_3(PO_4)_2.5H_2O$.—The water of crystallization may vary. Some varieties contain fluorine. Infusible. Soluble in hydrochloric acid.

Wavellite is a secondary mineral formed by the action of circulating waters containing phosphoric acid upon rocks and minerals rich in alumina. It is, hence, found on the surfaces of such rocks, or lining the cracks and cavities in the same. Some localities are: Devonshire and Cornwall, England; Bohemia; Chester and York Counties, Pennsylvania; Montgomery and Garland Counties, Arkansas; Silver Hill, South Carolina.

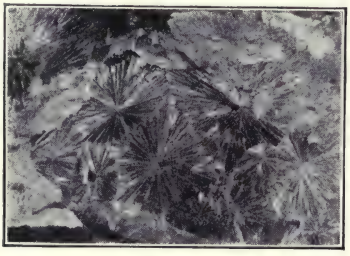


FIG. 573.—Wavellite. Arkansas.

FIG. 574.—Turquois. Los Cerrillos, Mexico.

**Turquois, $H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$.**

Triclinic. Crystals are tabular but very rare. Usually apparently amorphous, in reniform, botryoidal, or stalactitic masses and in veins; also as crusts, coatings (Fig. 574) and disseminated grains, or rolled and rounded pebbles.

Conchoidal fracture. Hardness 6. Specific gravity 2.6 to 2.8. Various shades of blue or green. Bluer in artificial light. Translucent to opaque. Waxy to dull luster. White or slightly greenish streak.

$H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$. Infusible. Soluble in acids after ignition.

Turquois is a secondary mineral and is often associated with limonite, quartz, feldspar, or kaolin. It occurs in trachyte near Nishapur in the province of Khorassan, Persia; Los Cerillos and elsewhere, New Mexico; Turquois Mountain, Arizona; San Bernardino County, California; Nye County, Nevada; Colorado.

Used as a gem mineral. Color fades in time and is destroyed by heat.

**Carnotite, $K_2O.2UO_3.V_2O_5.3H_2O$.**

Orthorhombic. Crystals are small, tabular, and with a rhombic outline. Usually observed in scaly aggregates, incrustations, or as a crystalline powder.

Perfect basal cleavage. Earthy fracture. Hardness 1 to 2. Canary to lemon yellow in color. Resinous to dull luster. Transparent to translucent.

A vanadate of potassium and uranium, containing small amounts of radium.

Occurs as a powdery incrustation in loosely cohering masses, or as an impregnation in sand or sandstone. Common associates are malachite, azurite, biotite, and magnetite. Occurs in Montrose County, Colorado; San Juan County, Utah; Mauch Chunk, Pennsylvania; Radium Hill, South Australia.

An important source of radium.

## 9. SILICATES AND TITANATES

This division contains a very large number of minerals, some of which are exceedingly common. For example, the members of the groups, known as the feldspars, pyroxenes, amphiboles, and micas, are very abundant and important as rock minerals. The feldspars alone make up 60 per cent. of the igneous rocks. For the most part, the chemical composition of these minerals is rather complex. In fact, in many cases, it is difficult to interpret a chemical analysis of a silicate mineral correctly, because the substance may be considered as a salt of several silicic acids.

Orthosilicic acid, $H_4SiO_4$, is taken as the basis for the derivation of the other silicic acids. By the loss of a molecule of water, it passes over to the metasilicic acid, $H_2SiO_3$. By the loss of water from several molecules of these acids, the more complex acids may be derived, as follows:

| | |
|---|---|
| Orthosilicic acid | $H_4SiO_4$ |
| Diorthosilicic acid | $H_6Si_2O_7$ $(2H_4SiO_4 - H_2O)$ |
| Trisilicic acid | $H_4Si_3O_8$ $(3H_4SiO_4 - 4H_2O)$ |
| Dimetasilicic acid | $H_2Si_2O_5$ $(2H_2SiO_3 - H_2O)$ |

The polysilicic acids are still more complex.

The following minerals include the most abundant and important silicates:

| | | |
|---|---|---|
| **STAUROLITE** | $HFeAl_5Si_2O_{13}$ | Orthorhombic |
| **HEMIMORPHITE** | $H_2Zn_2SiO_5$ | Orthorhombic |
| | ANDALUSITE GROUP | |
| **ANDALUSITE** | $Al_2SiO_5$ | Orthorhombic |
| Sillimanite | $Al_2SiO_5$ | Orthorhombic |
| **CYANITE** | $Al_2SiO_5$ | Triclinic |

| | | |
|---|---|---|
| **TOPAZ** | $Al_2(F,OH)_2SiO_4$ | Orthorhombic |
| Datolite | $Ca(B.OH)SiO_4$ | Monoclinic |
| **TOURMALINE** | $H_{20}B_2Si_4O_{21}$ | Hexagonal |
| Chondrodite | $[Mg(F,OH)]_2Mg_3(SiO_4)_2$ | Monoclinic |
| | Epidote Group | |
| **EPIDOTE** | $Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$ | Monoclinic |
| Orthite | $Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$ | Monoclinic |
| **VESUVIANITE** | $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$ | Tetragonal |
| | Olivine Group | |
| **OLIVINE** | $(Mg,Fe)_2SiO_4$. | Orthorhombic |
| Willemite | $Zn_2SiO_4$ | Hexagonal |
| **GARNET** | $R''_3R'''_2(SiO_4)_3$ | Cubic |
| **CHRYSOCOLLA** | $CuO,SiO_2,H_2O$ | Hexagonal or Tetragonal |
| | Mica Group | |
| **BIOTITE** | $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ | Monoclinic |
| **PHLOGOPITE** | $(K,H)_3Mg_3Al(SiO_4)_3$ | Monoclinic |
| **MUSCOVITE** | $H_2KAl_3(SiO_4)_3$ | Monoclinic |
| Lepidolite | $(Li,K)_2(F,OH)_2Al_2Si_3O_9$ | Monoclinic |
| **CHLORITE** | $H_8Mg_5Al_2Si_3O_{18}$ | Monoclinic |
| **SERPENTINE** | $H_4Mg_3Si_2O_9$ | Monoclinic |
| **TALC** | $H_2Mg_3Si_4O_{12}$ | Monoclinic |
| Sepiolite | $H_4Mg_2Si_3O_{10}$ | Monoclinic |
| Garnierite | $H_2(Ni,Mg)SiO_4$ | Amorphous |
| **KAOLINITE** | $H_4Al_2Si_2O_9$ | Monoclinic |
| **NEPHELITE** | $(Na,K)_8Al_8Si_9O_{34}$ | Tetragonal |
| Cancrinite | $H_6(Na_2,Ca)_4(NaCO_3)_2Al_8Si_9O_{36}$ | Hexagonal |
| Sodalite | $Na_4Al_2(AlCl)(SiO_4)_3$ | Cubic |
| Lazurite | $(Na_2,Ca)_2Al_2[Al(NaSO_4,NaS_3,Cl)](SiO_4)_3$ | Cubic |
| Ilmenite | $FeTiO_3$ | Hexagonal |
| | Pyroxene Group | |
| **ENSTATITE** | $(Mg,Fe)_2(SiO_3)_2$ | Orthorhombic |
| **DIOPSIDE** | $CaMg(SiO_3)_2$ | Monoclinic |
| Wollastonite | $Ca_2(SiO_3)_2$ | Monoclinic |
| **AUGITE** | $\left\{\begin{array}{l}(Mg,Fe)Ca(SiO_3)(SiO_3)\\(Mg,Fe)Al(AlO_3)(SiO_3)\\(Mg,Fe)Fe(FeO_3)(SiO_3)\end{array}\right\}$ | Monoclinic |
| Pectolite | $(Ca,Na_2)_2(SiO_3)_2$ | Monoclinic |
| **SPODUMENE** | $LiAl(SiO_3)_2$ | Monoclinic |
| **RHODONITE** | $Mn_2(SiO_3)_2$ | Triclinic |
| | Amphibole Group | |
| Tremolite | $CaMg_3(SiO_3)_4$ | Monoclinic |
| Actinolite | $Ca(Mg,Fe)_3(SiO_3)_4$ | Monoclinic |
| **HORNBLENDE** | $\left\{\begin{array}{l}Ca(Mg,Fe)_3(SiO_3)_2(SiO_3)_2\\Al_2(Mg,Fe)_3(AlO_3)_2(SiO_3)_2\\Fe_2(Mg,Fe)_3(FeO_3)_2(SiO_3)_2\end{array}\right\}$ | Monoclinic |
| Leucite | $K_2Al_2Si_4O_{12}$ | Pseudocubic |
| **BERYL** | $Be_3Al_2(SiO_3)_6$ | Hexagonal |

FELDSPAR GROUP

| | | |
|---|---|---|
| **ORTHOCLASE** | $KAlSi_3O_8$ | Monoclinic |
| **MICROCLINE** | $KAlSi_3O_8$ | Triclinic |
| **ALBITE** | $NaAlSi_3O_8$(Ab) | Triclinic |
| **LABRADORITE** | $Ab_1An_1$ to $Ab_1An_3$ | Triclinic |
| Anorthite | $CaAl_2Si_2O_8$(An) | Triclinic |
| **SCAPOLITE** | $\left\{ \begin{matrix} nNa_4Al_3Si_9O_{24}Cl \\ mCa_4Al_6Si_6O_{25} \end{matrix} \right\}$ | Tetragonal |
| **TITANITE** | $CaTiSiO_5$ | Monoclinic |

ZEOLITES

| | | |
|---|---|---|
| Natrolite | $Na_2Al(AlO)(SiO_3)_3.2H_2O$ | Monoclinic |
| **ANALCITE** | $Na_2Al_2(SiO_3)_4.2H_2O$ | Cubic |
| **APOPHYLLITE** | $H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$ | Tetragonal |
| **STILBITE** | $(Ca,Na_2)Al_2Si_6O_{16}.6H_2O$ | Monoclinic |
| **CHABAZITE** | $Ca\ Al_2Si_6O_{16}.8H_2O$ | Hexagonal |

These minerals are in general easily distinguished by their hardness, transparency, non-metallic luster, lack of characterizing colors, and uncolored streak.

**STAUROLITE, $HFeAl_5Si_2O_{13}$.**

Orthorhombic, bipyramidal class. Generally in well-developed prismatic crystals, consisting of the unit prism, basal and brachypinacoids, and a macrodome. Penetration twins according to two laws are common, yielding *cross-* or *plus-shaped* and *x-shaped twins* (Fig. 575).

FIG. 575.—Staurolite crystals —simple, plus- and X-shaped twins.

Brachypinacoidal cleavage. Conchoidal to uneven fracture. Hardness 7 to 7.5. Specific gravity 3.4 to 3.8. Usually reddish brown in color; also brownish black, yellowish brown, or gray when altered. Colorless streak when fresh. Vitreous to dull luster. Commonly translucent to opaque, rarely transparent.

FIG. 576.—Staurolite in schist. Little Falls, Minnesota.

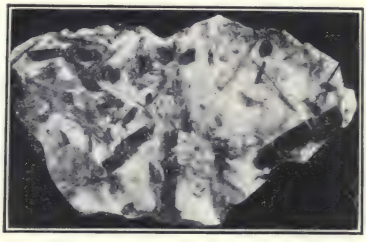


FIG. 577.—Staurolite (dark) in paragonite schist. Tepin, Switzerland.

$HFeAl_5Si_2O_{13}$. Composition varies greatly. May contain magnesium, manganese, and zinc. Often quite impure. Infusible. Insoluble in acids.

Occurs generally in metamorphic rocks, especially gneiss, mica schists, and slates (Fig. 576). The common associates are cyanite, garnet, tourmaline, and sillimanite. In the Saint Gothard district, Switzerland, it occurs with cyanite in paragonite (soda mica) schist (Fig. 577); also in Tyrol; France; Brazil; Fannin and Cherokee Counties, Georgia; Patrick County, Virginia; Ducktown, Tennessee; Grantham, New Hampshire; Windham, Maine; Chesterfield, Massachusetts; Litchfield, Connecticut.

Clear and transparent crystals are sometimes used for gem purposes.

**HEMIMORPHITE** (*Calamine*), $H_2Zn_2SiO_5$.

Orthorhombic, pyramidal class. Crystals are usually thin tabular or pyramidal in habit, sometimes showing a pronounced hemimorphic development (Fig. 579). Often arranged in sheaf-like or crested groups (Fig. 579). More commonly in fibrous, globular, granular, or porous and earthy masses.

Prismatic cleavage. Uneven to conchoidal fracture. Hardness 4.5 to 5. Specific gravity 3.3 to 3.5. Colorless, white, brown, green, or bluish. Transparent to opaque. Vitreous to dull luster.

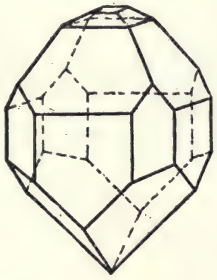


FIG. 578.

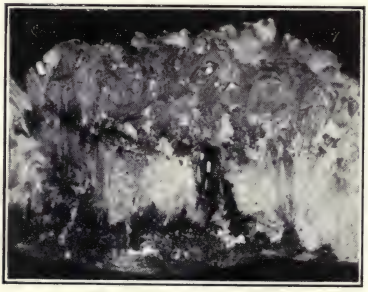


FIG. 579.—Hemimorphite. Chihuahua, Mexico.

$H_2Zn_2SiO_5$. Fuses with difficulty. Gelatinizes easily with acids. Occurs as a pseudomorph after calcite, galena, dolomite, fluorite, and pyromorphite.

Hemimorphite is a secondary mineral, formed by the action of silica bearing water upon other zinc ores, and is usually found in limestones associated with smithsonite, sphalerite, galena, cerussite, and anglesite. It is often intimately mixed with smithsonite. Some localities are: Aachen, Germany; Raibel and Bleiberg, Austria; Silesia; Cumberland and Derbyshire, England; Sardinia; Sussex County, New Jersey; Phoenixville and Friedensville, Pennsylvania; Granby and elsewhere, Missouri;

Pulaski and Wythe Counties, Virginia; Colorado; Utah; Tennessee; Arkansas.

Hemimorphite is an important ore of zinc.

## Andalusite Group

The compound $Al_2SiO_5$ is trimorphous and occurs in nature as the three minerals andalusite, sillimanite, and cyanite. The first two minerals crystallize in the orthorhombic system, while the third is triclinic. Andalusite and sillimanite are very closely related in many respects, and are considered salts of the orthosilicic acid. Cyanite is thought to be derived from the metasilicic acid.

FIG. 580.

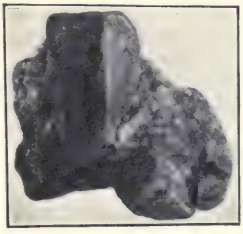


FIG. 581.—Andalusite. Andalusia, Spain.

**ANDALUSITE, $Al_2SiO_5$.**

Orthorhombic, bipyramidal class. Occurs usually in large, rough, and nearly square prismatic crystals (Figs. 580 and 581). *Chiastolite* is a variety with a regular internal arrangement of dark organic matter,

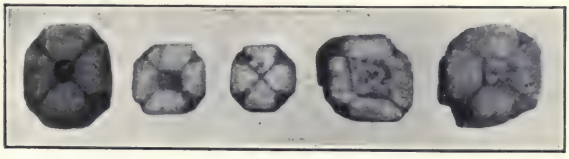


FIG. 582.—Andalusite: Variety, chiastolite. Lancaster, Massachusetts.

best seen in polished cross-sections (Fig. 582). Found also in fibrous, columnar, and granular masses, and in rounded pebbles.

Prismatic cleavage. Uneven fracture. Hardness 7 to 7.5, due to alteration may be softer on the surface. Specific gravity 3.1 to 3.2. Gray, greenish, reddish, or bluish in color. Transparent to opaque. Vitreous to dull luster. Sometimes strongly pleochroic.

$Al_2SiO_5$. Often impure. Infusible. Insoluble in acids. Alters to cyanite, mica, kaolinite, or dense talcose minerals resembling steatite.

Occurs in metamorphic rocks, especially in schists and slates. Com-

monly associated with cyanite, sillimanite, mica, garnet, and tourmaline. Some localities are: Andalusia, Spain; Tyrol; in transparent crystals in Minas Geræs, Brazil; Ceylon; Westford, Lancaster, and Sterling, Massachusetts; Litchfield and Washington, Connecticut; Standish, Maine; Madera County, California.

Transparent varieties are sometimes used for gem purposes.

**Sillimanite** (*Fibrolite*), $Al_2SiO_5$.

Orthorhombic. Usually in long, thin, needle-like crystals; or in radiating fibrous or columnar masses. Crystals are often bent, striated, interlaced, poorly terminated, and without sharp edges.

Macropinacoidal cleavage. Uneven fracture. Hardness 6 to 7. Specific gravity 3.2 to 3.3. Gray, brown, yellowish, or greenish in color. Vitreous or silky luster. Transparent to translucent.

$Al_2SiO_5$. Chemical composition and behavior are the same as for andalusite.

Occurs as an accessory constituent of gneisses, quartzites, mica schists, and other metamorphic rocks. It is sometimes associated with andalusite, zircon, or corundum. Found at Bodenmais, Bavaria; Freiberg, Saxony; Minas Geræs, Brazil; Worcester, Massachusetts; Norwich and Willimantic, Connecticut; Westchester and Monroe counties, New York; Chester, Pennsylvania.

FIG. 583. — Cyanite (bladed). Litchfield, Connecticut.

**CYANITE** (*Disthene, Kyanite*), $Al_2SiO_5$).

Triclinic, prismatic class. Generally in long, broad crystals without distinct terminations; or in coarse bladed, columnar, or fibrous masses (Fig. 583). Crystals are sometimes curved and arranged radially.

Macro- and brachypinacoidal cleavages. Hardness varies greatly with direction, 4 to 5 parallel to the long direction of the blades, 6 to 7 across them. Specific gravity 3.5 to 3.7. Generally some shade of blue in color; also grayish, white, green, brownish, or colorless. The edges are usually lighter in color than the central portions of the blades, that is, the color is distributed in streaks or spots. Vitreous luster. Transparent to translucent.

$Al_2SiO_5$. Chemical composition and behavior similar to that of andalusite and sillimanite. Cyanite is, however, more resistive to the action of acids.

Cyanite is a metamorphic mineral and is commonly found in gneisses and mica schists, especially paragonite schist. Usual associates are staurolite, garnet, corundum, rutile, and lazulite. Some localities are: the Saint Gothard district, Switzerland; various places in Tyrol; Sweden; Brazil; Chesterfield, Massachusetts; Litchfield and Washington,

Connecticut; Chester and Delaware counties, Pennsylvania; Gaston, Rutherford, and Yancey counties, North Carolina.

Sometimes used for gem purposes.

---

**TOPAZ, $Al_2(F,OH)_2SiO_4$.**

Orthorhombic, bipyramidal class. Generally in highly modified, prismatic crystals, which are usually developed on one end only (Figs. 584, 585 and 586). Often vertically striated. Occurs also in granular to compact masses, and in rolled fragments.

Very perfect basal cleavage. Conchoidal to uneven fracture. Hardness 8. Specific gravity 3.4 to 3.6. Colorless, wine yellow, grayish, violet, reddish, or bluish in color. Some colored varieties fade on exposure to sunlight. Transparent to opaque. Vitreous luster.

$Al_2(F,OH)_2SiO_4$. The percentages of fluorine and hydroxyl vary greatly. Infusible. Slightly acted upon by sulphuric acid. Sometimes alters to talc and kaolinite.

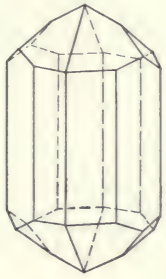


FIG. 584.

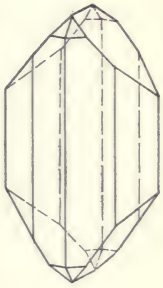


FIG. 585.

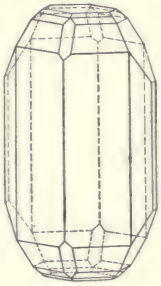


FIG. 586.

Topaz is a characteristic mineral of the pneumatolytic process of formation and is hence generally associated with cassiterite, tourmaline, quartz, fluorite, apatite, beryl, mica, scheelite, wolframite, and zircon. It occurs in crevices, cavities, and pegmatite dikes in highly acid igneous rocks such as granites, rhyolites, gneisses, and mica schists. Excellent crystals are found at Schneckenstein and elsewhere in Saxony; Ural Mountains; Sweden; Japan; Australia; Mexico; Thomas Range, Utah; Nathrop, Colorado; San Diego County, California; and various places in Connecticut, New Hampshire, and Maine. Frequently found in the sands and gravel of the streams of Ceylon, Brazil, and the Ural Mountains.

Clear and transparent crystals are used for gem purposes. The yellow variety from Brazil is often called *precious topaz*.

**Datolite, $Ca(B.OH)SiO_4$.**

Monoclinic, prismatic class. Usually prismatic, pyramidal, or tabular crystals, often highly modified (Figs. 587 and 588). Also in compact,

dull, or granular masses resembling wedgewood ware or unglazed porcelain (Fig. 589).

Conchoidal to uneven fracture. Hardness 5 to 5.5. Specific gravity 2.9 to 3. Colorless, white, or greenish, but often with yellowish, reddish, or brownish streaks and spots. Transparent to translucent, rarely opaque. Vitreous to dull luster.

$Ca(B.OH)SiO_4$. Crystals are usually very pure. Gelatinizes with hydrochloric acid.

Datolite is a secondary mineral and is generally found in cracks and cavities in basic igneous rocks, such as diorite, diabase, melaphyre, gabbro, and serpentine. The common associates are native copper, calcite, epidote, magnetite, and the zeolites. Some localities are: the Kilpatrick Hills, Scotland; Arendal, Norway; Hartz Mountains; Tyrol;

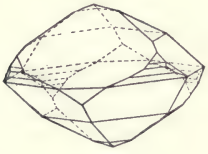


Fig. 587.

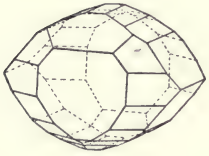


Fig. 588.

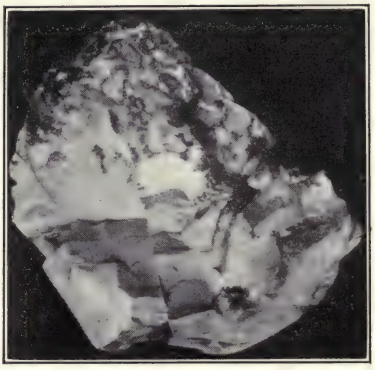


Fig. 589.—Datolite. Lake Superior Copper District.

Bergen Hill, New Jersey; Westfield and elsewhere, Massachusetts; Hartford, Connecticut; in the Lake Superior copper district excellent crystals and compact porcelain-like masses.

The massive varieties are sometimes used for gem purposes.

**TOURMALINE, $H_{20}B_2Si_4O_{21}$.**

Hexagonal, ditrigonal pyramidal class. Commonly in short to long prismatic crystals with vertical striations. Well-developed crystals have rhombohedral-like terminations and possess pronounced hemimorphism (Figs. 590, and 591). Crystals show a characteristic spherical triangular outline in cross-section (Figs. 592 and 593). Occurs also in compact and disseminated masses, and in radially divergent aggregates, called *tourmaline suns;* also in loose crystals in secondary deposits.

Conchoidal to uneven fracture. Hardness 7 to 7.5. Specific gravity 2.9 to 3.2. Usually pitch black or brown in color; also gray, yellow, green, or red, and more rarely colorless or white. The reddish varieties are frequently called *rubellite.* Zonal distribution of color is often very

marked, especially in crystals of the lighter colors (Fig. 593). Vitreous to resinous luster. Transparent to opaque. Strongly dichroic, and often pyroelectric.

$H_{20}B_2Si_4O_{21}$. A very complex silicate with varying amounts of iron, aluminum, magnesium, manganese, calcium, lithium, sodium, potassium, hydroxyl, and fluorine. Sometimes classified according to composition as lithium, iron, and magnesium tourmalines. Fusibility varies greatly.

FIG. 590.

FIG. 591.

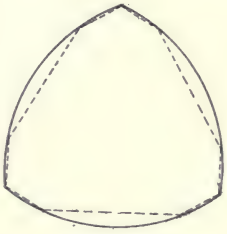


FIG. 592.

Insoluble in acids, but gelatinizes after fusion or strong ignition. Alters to muscovite, biotite, or chlorite.

Tourmaline is a very characteristic mineral of pegmatite dikes associated with intrusions of granite. It is the result of pneumatolytic action as is evidenced by the presence of fluorine, hydroxyl, and boron. It is also rather common in metamorphic rocks, such as gneisses, schists, and in crystalline limestones and dolomites. Some of the common

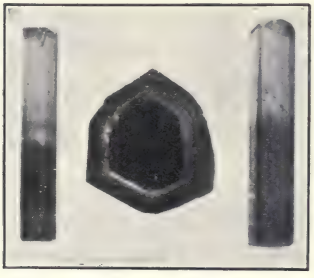


FIG. 593.—Tourmaline showing zonal distribution of color and spherical triangular outline. San Diego County, California.

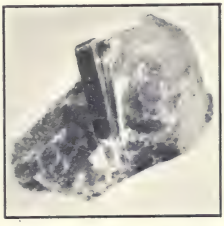


FIG. 594.—Tourmaline in quartz. Auburn, Maine.

FIG. 595.—Tourmaline in albite. Mesa Grande, California.

associates are quartz (Fig. 594), feldspar (Fig. 595), beryl, topaz, fluorite, lepidolite (Fig. 596), apatite, and muscovite. Excellent crystals occur on the Island of Elba; in Ural Mountains; Burma; Ceylon; Madagascar; Minas Geraes, Brazil; Paris, Auburn, and Rumford, Maine; Haddam Neck, Connecticut; Gouverneur and elsewhere in Saint Lawrence County, New York; Mesa Grande, Pala, and elsewhere in San Diego County, California.

Stones of good colors are used for gem purposes. On account of its strong absorption of light it has been used in the making of tourmaline tongs, a simple instrument for the production of polarized light.

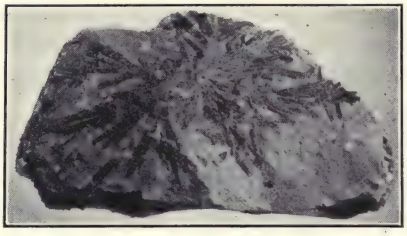


FIG. 596.—Tourmaline: Variety, rubellite, in lepidolite. San Diego County, California.

**Chondrodite** $[Mg(F,OH)]_2Mg_3(SiO_4)_2$.

Monoclinic, prismatic class. Occurs in small, highly modified, pseudo-orthorhombic crystals, also in grains or lumps, and in granular aggregates.

Basal cleavage. Uneven to conchoidal cleavage. Hardness 6 to 6.5. Specific gravity 3.1 to 3.3. Brown, yellow, or red in color. Vitreous to resinous luster. Translucent to opaque.

$[Mg(F,OH)]_2Mg_3(SiO_4)_2$. Some of the magnesium may be replaced by bivalent iron. Infusible. Gelatinizes with hydrochloric acid. Alters to serpentine and brucite.

Chondrodite is a typical contact metamorphic mineral. It occurs commonly in crystalline limestones and dolomites, associated with spinel, vesuvianite, magnetite, pyroxene, and phlogopite. Some important localities are: Pargas, Finland; Mount Vesuvius; Burma; Sparta, New Jersey; Tilly Foster mine, near Brewster, and in Orange County, New York.

## Epidote Group

Under this heading two rather complex but isomorphous silicates of calcium and aluminum will be described.

**EPIDOTE,** $Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$.

Monoclinic, prismatic class. Excellent prismatic and highly modified crystals are rather common; usually elongated and deeply striated parallel to the *b* axis, and terminated at one end only (Figs. 597 and 598). Occurs also in divergent or parallel fibrous and columnar aggregates, coarse to fine granular masses, or in rounded or angular grains.

Basal cleavage. Uneven fracture. Hardness 6 to 7. Specific gravity 3.3 to 3.5. Yellowish to blackish green in color; more rarely red or colorless. Crystals are usually darker in color than massive varieties. Vitreous to resinous luster. Transparent to opaque. Strongly pleochroic.

$Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$. The percentages of the oxides of calcium, iron, aluminum, and silicon vary considerably. *Clinozoisite* contains little or no iron. *Zoisite* is an orthorhombic modification. Loses water when strongly ignited, and gelatinizes with hydrochloric acid after ignition. Occurs as a pseudomorph after scapolite, garnet, augite, and hornblende.

Epidote is a typical metamorphic mineral. It is found in such rocks as gneiss, and schists of various kinds; often occurs very extensively, forming *epidote rocks and schists.* It is commonly associated with garnet, vesuvianite, hornblende, hematite, native copper, magnetite, and the zeolites. It is also a common alteration product of minerals high in calcium and aluminum, such as feldspar, pyroxene, amphibole, scapolite, and biotite. Important localities are: Zillerthal and Untersulzbachthal, Tyrol; Travesella, Piedmont; Island of Elba; Dauphine, France; Arendal, Norway; Ural Mountains; Haddam, Connecticut; various places in New

FIG. 597.

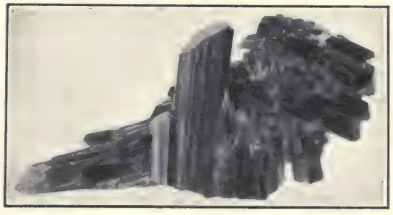


FIG. 598.—Epidote. Untersulzbachthal, Tyrol.

York, New Jersey, and Colorado; with native copper in the Lake Superior copper district.

The clear and transparent dark green crystals are sometimes used for gem purposes.

**Orthite** (*Allanite*), $\mathbf{Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3}$.

Monoclinic, prismatic class. Crystals are tabular or prismatic, but rare. Usually in massive, granular, or bladed aggregates; also as disseminated grains.

Uneven to conchoidal fracture. Hardness 5.5 to 6. Specific gravity 3 to 4. Pitch black in color, sometimes brownish or grayish; often coated with a yellowish or brownish alteration product. Greenish gray to brown streak. Pitchy submetallic luster. Opaque.

$Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$. Composition varies greatly. Didymium, lanthanum, yttrium, magnesium, and water may be present. Fuses easily with intumescence to a black magnetic glass. Gelatinizes with hydrochloric acid, but not if previously ignited.

Orthite occurs in small quantities in igneous rocks, such as granites and pegmatites; also in gneiss, mica and amphibolite schists, and crystalline limestones. Commonly associated with epidote, magnetite, quartz,

and feldspar. Occurs in Greenland; Falun, Sweden; Miask, Ural Mountains; Edenville, New York; Haddam, Connecticut; Franklin, New Jersey; Madison and Iredell counties, North Carolina; Barringer Hill, Texas; Amherst County, Virginia.

---

**VESUVIANITE** (*Idocrase*), $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$.

Tetragonal, ditetragonal bipyramidal class. Crystals are generally short prismatic (Figs. 599, 600, and 601), rarely pyramidal or acicular. Occurs also in compact and granular masses, and in aggregates with parallel or divergent striations or furrows.

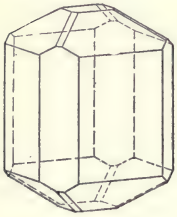


Fig. 599.

Uneven fracture. Hardness 6.5. Specific gravity 3.3 to 3.5. Occurs in many shades of yellow, green, and brown; more rarely blue, red, or nearly black. *Californite* is a compact green variety with colorless or white streaks, resembling jade. Vitreous greasy luster. Commonly translucent.

$Ca_6[Al(OH,F)]Al_2(SiO_4)_5$. The composition is complex and variable. May contain titanium, boron, iron, magnesium, manganese, sodium, potassium, and lithium. Fuses with intumescence to a greenish or brownish glass. After ignition, it decomposes easily with acids.

Vesuvianite is a typical contact metamorphic mineral. It is found commonly in crystalline limestones, gneiss, and schists, associated with

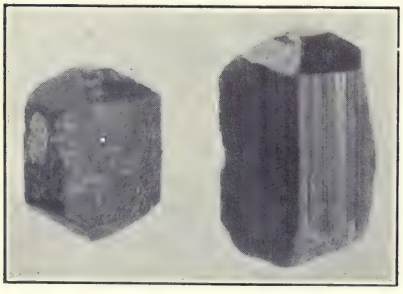


Fig. 600.—Vesuvianite. (*a*) Wilui River, Siberia; (*b*) Achmatovsk, Russia.

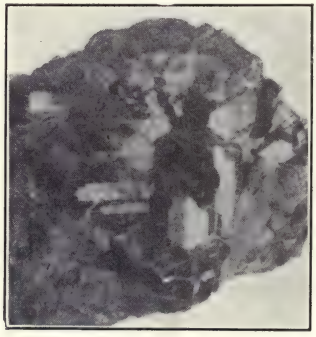


Fig. 601.—Vesuvianite. Fassathal, Tyrol.

garnet, tourmaline, chondrodite, wollastonite, epidote, and the pyroxenes. Important localities are: Monzoni, Tyrol; Ala Valley, Piedmont; Vesuvius; Morelos, Mexico; Eger, Hungary; Wilui River, Siberia; Rumford, Maine; Amity, New York; various places in California, Ontario, and Quebec.

Clear and transparent brown and green varieties are used for gem purposes.

## Olivine Group

This group contains minerals which are normal orthosilicates. Only two members of the group occur abundantly enough to be described.

**OLIVINE** (*Chrysolite, Peridot*), **$(Mg,Fe)_2SiO_4$.**

Orthorhombic, bipyramidal class. Crystals are prismatic (Fig. 602) or thick tabular. Occurs generally in rounded, disseminated, glassy grains (Fig. 603), granular aggregates, or in rounded loose pebbles.

Pinacoidal cleavages. Conchoidal fracture. Hardness 6.5 to 7. Specific gravity 3.2 to 3.6. Vitreous luster. Commonly various shades of green, also yellowish, brown, reddish, grayish, or colorless. Transparent to translucent.

$(Mg,Fe)_2SiO_4$. The composition varies between that of forsterite, $Mg_2SiO_4$, and fayalite, $Fe_2SiO_4$. Titanium, nickel, and calcium may be present in small amounts. Infusible. Easily decomposed and gelatinizes with acids. Alters to serpentine, limonite, magnesite, opal, and garnierite.

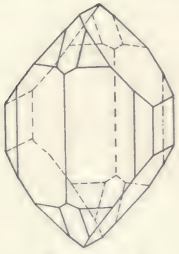


FIG. 602.

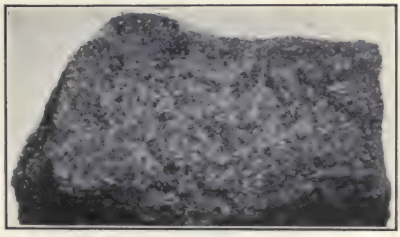


FIG. 603.—Olivine (green glassy grains). Near Balsam, North Carolina.

Olivine is a constituent of many basic igneous rocks, such as basalt, gabbro, and peridotite. Found also in crystalline limestones. The common associates are augite, enstatite, spinel, plagioclase, chromite, pyrope, corundum, talc, and magnetite. Occurs in northern Egypt; Mount Vesuvius; Upper Burma; Snarum, Norway; Arizona; Vermont; New Hampshire; Virginia; Pennsylvania; Oregon; New Mexico; Canada; Brazil.

*Peridot* is a transparent green variety used for gem purposes.

**Willemite, $Zn_2SiO_4$.**

Hexagonal, trigonal rhombohedral class. Crystals are either slender or thick prismatic in habit, but generally quite small. *Troostite*, a variety containing manganese, is commonly found in larger crystals. Occurs also in compact, or granular masses, and in disseminated grains (Fig. 604).

Basal Cleavage. Uneven fracture. Hardness 5 to 6. Fracture 3.9 to 4.3. Greasy vitreous luster. Commonly yellow, green, brown, or

reddish; more rarely blue, black, white, or colorless. Transparent to opaque.

$Zn_2SiO_4$. Manganese and iron may be present. Fuses with difficulty. Gelatinizes with hydrochloric acid. Sometimes pseudomorphous after calamine.

The usual associates are franklinite, zincite, rhodonite, and calcite. The most important locality is Franklin Furnace and vicinity, Sussex County, New Jersey, where it occurs in large quantities. Found also at Altenberg, near Aachen, Germany; Musartut, Greenland; Merritt Mine, Socorro County, New Mexico; and Clifton, Arizona.

Willemite is an important ore of zinc.

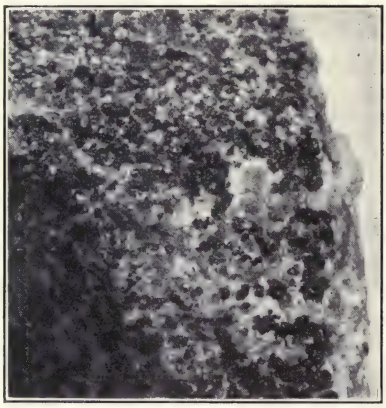


FIG. 604.—Willemite (light) with Franklinite. Franklin Furnace, New Jersey.

## Garnet Group

This group embraces minerals possessing the general formula, $R''_3R'''_2(SiO_4)_3$, in which R'' may be calcium, magnesium, manganese, or ferrous iron, and R''' aluminum, ferric iron, or chromium. Sometimes titanium may replace a portion of the silicon. Six varieties depending upon composition have been distinguished.

| | |
|---|---|
| Grossularite | $Ca_3Al_2(SiO_4)_3$ |
| Pyrope | $Mg_3Al_2(SiO_4)_3$ |
| Spessartite | $Mn_3Al_2(SiO_4)_3$ |
| Almandite | $Fe_3Al_2(SiO_4)_3$ |
| Uvarovite | $Ca_3Cr_2(SiO_4)_3$ |
| Andradite | $Ca_3Fe_2(SiO_4)_3$ |

These varieties grade over into one another, the composition of a given specimen being usually rather complex.

Cubic, hexoctahedral class. Crystals are usually rhombic dodecahedrons or tetragonal trisoctahedrons, often in combination (Figs. 605 to 609). The hexoctahedron is quite frequently observed (Fig.

607). Other forms are rare. Generally well crystallized, but occurs also as rounded disseminated glassy grains, and in compact granular aggregates.

Indistinct dodecahedral cleavage. Conchoidal to uneven fracture. Hardness 6.5 to 7.5. Specific gravity 3.4 to 4.3, varying with the composition. Commonly red, brown, yellow, green, or black; less frequently

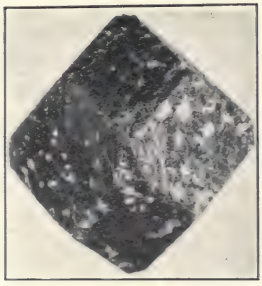


FIG. 605.—Garnet (rhombic dodecahedron). Salida, Colorado.

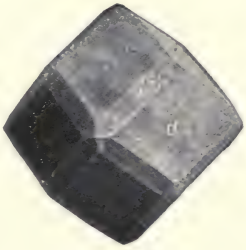


FIG. 606.

FIG. 607.

white or colorless. Light colored garnets are generally transparent to translucent, dark colored varieties translucent to opaque. Vitreous to resinous luster.

$R''_3R'''_2(SiO_4)_3$. Composition varies greatly as indicated above. The chemical properties of the six varieties differ materially. They generally fuse easily to a brownish or black glass, which is sometimes mag-

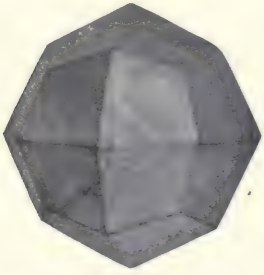


FIG. 608.

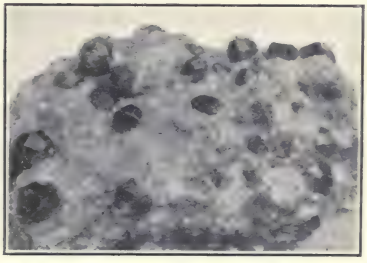


FIG. 609.—Garnet (tetragonal trisoctahedrons) in mica schist. Sunday River, Maine.

netic. With the exception of uvarovite, all varieties gelatinize with acids after fusion. Garnets alter readily; epidote, mica, chlorite, serpentine, hornblende, scapolite, orthoclase, calcite, and limonite have been observed occurring as pseudomorphs after garnet. Large chlorite pseudomorphs after garnet occur at Spurr Mountain Mine, Lake Superior region.

Garnet is a very common mineral. It occurs in crystalline schists,

as a contact metamorphic mineral, as a constituent of many eruptive rocks, with various ores, and in secondary deposits.

**Grossularite, Hessonite, Cinnamon Stone.**—Calcium-aluminum garnet. Calcium may be partially replaced by ferrous iron, and aluminum by ferric iron. Specific gravity varies from 3.4 to 3.7. White, various shades of yellow, cinnamon brown, rose red; also green and colorless. It occurs in crystalline limestones and dolomites with wollastonite, vesuvianite, diopside, and scapolite. Some localities are: Ceylon; Mussa Alp, Piedmont; Wilui River, Siberia; Morelos, Mexico; Monzoni, Tyrol; Rumford, Maine; Warren, New Hamsphire. Yellow and orange grossularites are used for gem purposes.

**Pyrope.**—Magnesium-aluminum garnet. Calcium and ferrous iron may partially replace magnesium. Specific gravity 3.7. Deep red to almost black. When clear and transparent is often called precious garnet and used as a gem. Commonly known as *Cape ruby* or *Arizona ruby*. Found usually in basic igneous rocks, such as peridotite or serpentine. Frequently considered an important associate of the diamond. Rarely found in good crystals, usually in irregular particles or rounded grains. Important localities are Teplitz, Aussig, and Bilin, Bohemia; Kimberley and other diamondiferous localities in South Africa; various places in Arizona and New Mexico.

**Spessartite.**—Manganese-aluminum garnet. May contain ferrous and ferric iron. Specific gravity 4 to 4.3. Brownish to hyacinth red. Occurs in granitic rocks with topaz, tourmaline, quartz, and orthoclase. Occurs in Tyrol; Piedmont; Ceylon; Haddam, Connecticut; Amelia Court House, Virginia; Bethel, Maine; Salem, North Carolina.

**Almandite, Carbuncle.**—Iron-aluminum garnet. May contain magnesium and ferric iron. Specific gravity 3.9 to 4.2. Deep red to brownish red or black in color. Transparent red varieties are known as precious garnets and used as gems; translucent varieties are called common garnets. Commonly found in mica and other schists, associated with staurolite, cyanite, andalusite, and tourmaline. Excellent specimens are obtained in India; Ceylon; Minas Novas, Brazil; Bodö, Norway; Tyrol; Uruguay; Australia; Salida, Colorado; Fort Wrangel, Alaska; Charlemont, Massachusetts. *Rhodolite* is a pale violet variety, between pyrope and almandite, occurring in Macon County, North Carolina.

**Uvarovite.**—Calcium-chromium garnet. Emerald green in color. Crystals are usually small. Not a common variety. Found with chromite in serpentine or in crystalline limestones and gneiss. Some localities are Ural Mountains; Oxford, Canada; New Idria, California.

**Andradite.**—Calcium-iron garnet. The composition varies greatly. The color may be brownish red, brown, grayish black, black, also various shades of yellow or green. *Topazolite* is yellowish or greenish, and often resembles topaz. *Demantoid* is a grass green variety. *Melanite* is black.

These garnets occur in syenite, serpentine, chloritic schists, and crystalline limestones. Common associates are feldspar, nephelite, leucite, epidote, and magnetite. Found at Dobschau, Hungary; Tyrol; Island of Elba; Arendal, Norway; Ural Mountains; Franklin, New Jersey; Magnet Cove, Arkansas; Henderson, North Carolina.

Pyrope and almandite furnish most of the garnets used as gems. Almandite and andradite are often called common garnets. Small garnets are sometimes used as jewels in watches of a cheaper grade. Massive and compact garnet is used as an abrasive and for making sandpaper. In 1916, 6,171 short tons of garnet were produced in the United States for abrasive purposes.

---

**CHRYSOCOLLA, $CuO$, $SiO_2$, $H_2O$.**

Usually apparently amorphous. Tetragonal or hexagonal. Crystals are small, acicular, and very rare. Occurs in compact, reniform, or earthy masses; also as incrustations and stains, and in veins. May have an enamel-like appearance and resemble opal.

Conchoidal fracture. Hardness 2 to 4. Specific gravity 2 to 2.2. Usually various shades of green or blue; when impure, brown to black. Translucent to opaque. Vitreous, greasy, or dull luster.

Chemically chrysocolla is considered a solid solution of $CuO$, $SiO_2$, and $H_2O$ in varying proportions. Infusible. Decomposed by acids but does not gelatinize. Forms pseudomorphs after atacamite, azurite, and cerussite.

Chrysocolla is a secondary mineral, formed by the alteration of various copper ores, such as chalcopyrite, cuprite, and tetrahedrite. Generally found in the zone of oxidation of copper deposits. It is commonly associated with malachite, native copper, azurite, and limonite. Some localities are: Cornwall, England; Ural Mountains; Clifton and Bisbee copper districts, Arizona; Wyoming; Nevada; New Mexico; Lake Superior copper district; in fact all important copper localities.

It is an ore of copper. It is sometimes cut and polished for gem purposes. At times it is substituted for turquois.

### Mica Group

Although the members of the mica group vary greatly from the chemical standpoint, they have, nevertheless, many characteristics in common. Crystals are apparently hexagonal or orthorhombic in development, but they all belong to the monoclinic system. The prism angle usually approximates 120°. Twins are not uncommon. The micas possess an excellent basal cleavage, which is sometimes considered the most perfect cleavage to be observed on minerals. Cleavage laminæ are elastic.

The micas are silicates of varying compositions of aluminum and

potassium, containing hydrogen, magnesium, iron, sodium, lithium, and fluorine. The silica content varies between 33 per cent. and 55 per cent. Several theories have been advanced to explain the rather complex composition of the members of this group. According to Clarke, the micas are derived from the hypothetical orthosilicate $Al_4(SiO_4)_3$, while Tschermak considers them as mixtures in varying proportions of $H_3Al_3(SiO_4)_3$ and $(Mg,Fe)_6(SiO_4)_3$.

The following four varieties occur extensively, and are to be considered among the most common and important minerals.

Biotite, $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$.

Phlogopite, $(K,H)_3Mg_3Al(SiO_4)_3$.

Muscovite, $H_2KAl_3(SiO_4)_3$.

Lepidolite, $(Li,K)_2(F,OH)_2Al_2Si_3O_9$.

All of the micas yield water when heated in a closed tube. They fuse with difficulty. They are important rock forming minerals, being essential constituents of many igneous and metamorphic rocks. Some sedimentary rocks often contain considerable quantities of mica.

**BIOTITE** (*Magnesium-iron Mica, Black Mica*), $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$.

Monoclinic, prismatic class. Crystals are usually tabular with an hexagonal (Fig. 610) or rhombohedral habit; sometimes striated horizontally. Crystals are rare. Generally found in plates, lamellar masses, or disseminated scales.

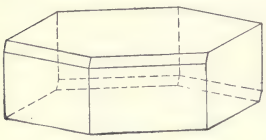


Fig. 610.

Highly perfect basal cleavage. Hardness 2.5 to 3. Specific gravity 2.7 to 3.2. Dark brown or black in color; more rarely, light brown, or greenish. White to greenish streak. Transparent to opaque. Sometimes shows asterism. $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$. The composition varies greatly. May contain titanium, sodium, and fluorine. *Lepidomelane* contains large amounts of the oxides of iron and but little MgO. Fuses with difficulty. Only slightly attacked by hydrochloric acid; completely decomposed by hot concentrated sulphuric acid. Alters to chlorite, or to epidote, quartz, and iron oxide.

Biotite is an extremely common mica, being an important constituent of many igneous and metamorphic rocks, such as, granite, syenite, diorite, porphyry, gneiss, and mica schists. It is often associated with muscovite.

Biotite is of little use commercially.

**Phlogopite** (*Magnesium Mica, Amber Mica, Bronze Mica*), $(K,H)_3Mg_3Al(SiO_4)_3$.

Monoclinic, prismatic class. Crystals usually resemble those of biotite in form and habit, and are sometimes large and coarse (Fig. 611).

They may be hexagonal or orthorhombic in outline. Commonly found in disseminated scales, plates, or aggregates.

Highly perfect basal cleavage. Thin laminæ are tough and elastic. Specific gravity 2.8 to 3. Pearly to submetallic luster. Color may be silvery gray, yellow, brown, green, copper or bronze red. Thin leaves are transparent. Often shows asterism.

$(K,H)_3Mg_3Al(SiO_4)_3$. Usually contains small amounts of iron, sodium, and fluorine. Whitens and fuses on thin edges. Slightly acted upon by hydrochloric acid, but readily decomposed by hot concentrated sulphuric.

FIG. 611.—Phlogopite. Lanark County, Ontario.

Phlogopite occurs in crystalline limestones, dolomites, schists, and in serpentine. Important localities are: Pargas, Finland; Aeker, Sweden; Fassathal, Tyrol; St. Lawrence and Jefferson counties, New York; Morris and Warren counties, New Jersey; Sydenham and Burgess, Ontario, where crystals measuring seven feet across the cleavage plane have been found; various localities in Quebec.

It is used chiefly as an insulator in electrical apparatus. For use on commutators, phlogopite is preferred to muscovite as it has more nearly the same hardness as the copper of the commutator segments.

**MUSCOVITE** (*White Mica, Potash Mica, Isinglass*), $H_2KAl_3(SiO_4)_3$.

Monoclinic, prismatic class. Crystals are usually tabular, and possess an orthorhombic or hexagonal outline (Figs. 612 and 613).

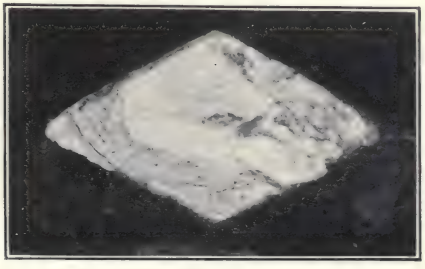


FIG. 612.—Muscovite (orthorombic outline). Buckfield, Maine.

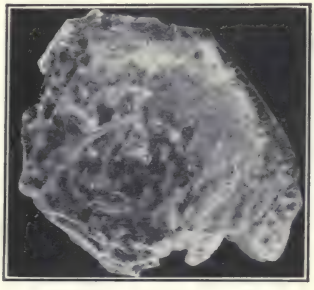


FIG. 613.—Muscovite (hexagonal outline) bordered with lepidolite. Auburn, Maine.

Tapering pyramidal habits are also observed. Crystals are often large and rough, measuring at times several feet in diameter. Large crystals may show distinct partings perpendicular to the cleavage, and are then called *ruled, ribbon,* or *A* mica. The term *wedge* mica is applied to crystals

that are thicker at one end than at the other. Usually occurs in scaly, foliated, and plumose aggregates.

Highly perfect basal cleavage, permitting very thin, transparent, and elastic leaves to be split. Hardness 2 to 3. Specific gravity 2.8 to 3.1. Colorless, yellowish, brownish, or reddish. Transparent to translucent. Pearly to vitreous luster.

$H_2KAl_3(SiO_4)_3$. Frequently contains small amounts of calcium, magnesium, iron, sodium, and fluorine. *Fuchiste* contains small amounts of chromium, while *roscoelite* has considerable vanadium replacing the aluminum. Fuses with difficulty to a grayish or yellowish glass. Not attacked by common acids *Sericite* is a variety consisting of fine scaly aggregates with a silky luster. It often results from the alteration of feldspars.

Muscovite is generally considered the most common mica. It occurs in granites and syenites, and especially in pegmatite veins where pneumatolytic action has been effective. It is also common in metamorphic rocks, such as gneisses and schists, and in some limestones and fragmental rocks. The usual associates are feldspar, quartz, tourmaline, beryl, spodumene, garnet, apatite, and fluorite. Deposits of muscovite of commercial value occur in North Carolina, New Hamsphire, South Dakota, Idaho, New Mexico, Colorado, Virginia, South Carolina, Georgia, and Alabama. Some of the principal producing localities are in Mitchell, Yancey, Macon, Jackson, Haywood, and Ashe Counties, North Carolina; Custer County, South Dakota; Grafton and Cheshire counties, New Hampshire. Deposits of excellent muscovite also occur in Ottawa and Berthier counties, Quebec.

Sheet mica is used principally in the manufacture of electrical apparatus and machinery such as dynamos, motors, high voltage induction apparatus, switchboards, lamp sockets, and for flexible mica-covered insulating cloth and tape. Clear and transparent sheets are used for windows in coal, gas, and oil stoves, gas-lamp chimneys, and lamp shades. Scrap mica, that is, material too small to be cut into sheets, is ground in large quantities and used in the manufacture of wall paper, lubricants, fancy paints, rubber goods, electrical insulators, coverings for steam pipes, and roofing papers.

*Micanite* is prepared by cementing with shellac successive layers of small, thin sheets of mica and subjecting the mass to heat and pressure.

United States consumes about 75 per cent. of the world's production of mica; 80 to 90 per cent. is of domestic origin, the remainder being imported from Canada and India. The total value of the domestic mica production in United States in 1918 was $731,810, representing the value of 1,644,200 lbs. of sheet mica and 2,292 short tons of scrap mica.

**Lepidolite** (*Lithium Mica*), $(Li,K)_2(F,OH)_2Al_2Si_3O_9$.

Monoclinic, prismatic class. Crystals are short prismatic, but very rare. Usually in scaly, granular masses, often resembling granular limestone, and in tabular, cleavable plates.

Perfect basal cleavage. Hardness 2 to 4. Specific gravity 2.8 to 2.9. Rose-red or lilac in color, also white, gray, greenish, or brown. Pearly luster. Translucent.

$(Li,K)_2(F,OH)_2Al_2Si_3O_9$. Some varieties contain rubidium and caesium. Colors the flame red and fuses to a white glass. After fusion easily acted upon by acids.

Occurs commonly in pegmatite veins, also in granites and gneisses. It is usually the result of pneumatolytic action. The common associates are tourmaline (especially rubellite), (Fig. 596, page 286), spodumene, cassiterite, muscovite, albite, and topaz. Some localities are: Rozena, Moravia; Island of Elba; Paris, Hebron, Auburn, and Rumford, Maine; Chesterfield, Massachusetts; San Diego County, California.

An important source of lithium compounds.

---

**CHLORITE,** *Prochlorite, Clinochlorite,* $H_8Mg_5Al_2Si_3O_{18}$.

The general term chlorite is applied to a number of minerals which are closely related to the micas.

Monoclinic, prismatic class. Crystals are tabular and six-sided, resembling those of mica. Commonly in foliated, scaly, granular, or earthy masses. Often as a scaly or dusty coating on, or disseminated through, quartz, titanite, pericline, and adularia.

Perfect basal cleavage. Laminæ are flexible but inelastic. Slightly soapy feel. Hardness 1 to 2.5. Specific gravity 2.6 to 3. Grass green, brownish green, or blackish green in color. Translucent to opaque, very thin laminæ may be transparent. Streak, greenish.

The minerals included in this description are silicates of aluminum or trivalent iron with magnesium, bivalent iron, or manganese. They are more basic than the micas, and are free from the alkalies and calcium. The composition varies greatly. They yield water when heated in a closed tube.

These minerals are of secondary origin, and are usually the result of the decomposition of pyroxenes, amphiboles, garnet, biotite, and vesuvianite. Very common in schists and serpentine. Often associated with garnet, diopside, magnesite, magnetite, and apatite. Very widespread. Some principal localities are: Ural Mountains; various places in Tyrol; Zermatt, Switzerland; Saxony; Chester and Unionville, Pennsylvania; Brewster, New York.

**SERPENTINE,** $H_4Mg_3Si_2O_9$.

Monoclinic, optically. Never in crystals except pseudomorphs. Usually compact, columnar, fibrous, or lamellar. Massive varieties often have a microscopically fine fibrous or foliated structure.

Conchoidal to splintery fracture. Hardness 2.5 to 4. Specific gravity 2.5 to 2.8. Various shades of green, also yellowish, grayish, reddish, brownish, or black. Often spotted, clouded, or multi-colored. Dull resinous, greasy, or waxy luster. Smooth to greasy feel.

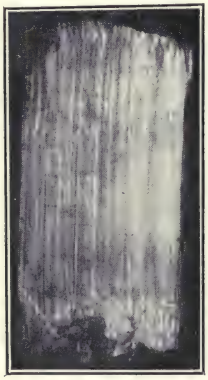


FIG. 614.—Serpentine: Variety, asbestos. Near Globe, Arizona.

FIG. 615.—Serpentine: Variety, asbestos (light). Thetford Lake District, Canada.

There are several varieties:

(1) *Common Serpentine.*—Compact, massive. Generally dark in color, often multi-colored. Sometimes impure. Very abundant.

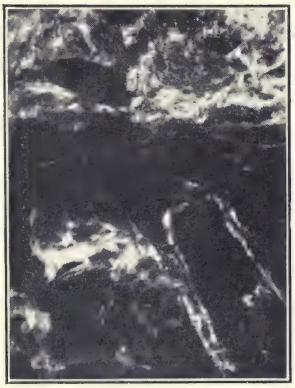


FIG. 616.—Serpentine: Variety, verd-antique. Roxbury, Vermont.

(2) *Precious Serpentine.*—Massive, more or less homogeneous. Various shades of green in color, sometimes yellowish. Translucent.

(3) *Chrysotile, Fibrous Serpentine, Asbestos.*—Consist of delicate, fine, parallel fibers, which can be easily separated (Fig. 614). Fibers are flexible and adapted for spinning. Silky to silky metallic luster. Various shades of green in color, also white, yellowish or brownish Usually found in veins with the fibers perpendicular to the walls of the veins (Fig. 615). Sometimes called *short fibered asbestos.*

(4) *Verd-antique.*—Massive greenish serpentine mixed irregularly with calcite, dolomite, or magnesite, having a mottled or veined appearance (Fig. 616). Takes an excellent polish and is used extensively for ornamental purposes. It is sometimes called *serpentine marble.*

$H_4Mg_3Si_2O_9$. May contain iron and nickel. Yields water when ignited. Splinters fuse with difficulty. Decomposed by acids with a

separation of silica. May alter to brucite, magnesite, and hydromagnesite. Serpentine is a secondary mineral resulting from the alteration of magnesium minerals and rocks, such as olivine, enstatite, hornblende, tremolite, augite, chondrodite, and peridotite. Olivine is the most common source of serpentine. Common associates are magnesite, calcite, chromite, garnierite, pyrope, platinum, and talc.

Serpentine occurs in many localities, some of which are: Sweden; Silesia; Chester County and Easton, Pennsylvania, where it is mined; Milford, Connecticut; Hoboken and Montville, New Jersey; Syracuse, New York; Vermont; northern New York; Washington. Asbestos is not found to any extent in the United States. Most of the asbestos of commerce is obtained from the mines in the Thetford-Black Lake district, Quebec. In 1918, the imports of asbestos, almost wholly from Canada, amounted to 137,700 short tons.

Polished massive serpentine and verd-antique are used for ornamental and interior decorative purposes. Translucent yellowish serpentine is sometimes cut and polished for gem purposes. Asbestos is used extensively in the manufacture of non-conductors of heat and in non-combustible materials such as cloth, boards, felt, rope, paper, paint, cement, and theater curtains.

**TALC, $H_2Mg_3Si_4O_{12}$.**

Monoclinic. Crystals are tabular or scaly, but indistinctly developed. Occurs usually as foliated or compact masses, and globular or stellate groups; also fibrous or granular.

Perfect basal cleavage. Laminæ are flexible but inelastic. Compact varieties have an uneven fracture. Hardness 1 to 2.5. Specific gravity 2.6 to 2.8. Commonly green, white, or gray in color; also yellowish, reddish, and brown. Greasy or soapy feel. Opaque to transparent.

There are several varieties of talc:

(1) *Foliated Talc.*—Consists of easily separable but inelastic scales or plates. Soapy or greasy feel. Hardness 1, easily impressed by the finger nail. Light green to white in color.

(2) *Steatite or Soapstone.*—Massive, often impure. Coarse to fine granular, also schistose. Gray to greenish in color. Hardness 1.5 to 2.5. Occurs in large deposits.

(3) *French Chalk.*—Soft, compact, whitish masses. Marks cloth easily.

$H_2Mg_3Si_4O_{12}$. May contain iron, aluminum, and nickel. Fuses with great difficulty. Yields water when strongly ignited. Unattacked by acids. Occurs as a pseudomorph after pyroxene, hornblende, tremolite, enstatite, spinel, quartz, dolomite, and many other minerals.

Talc is usually considered an alteration product of non-aluminous magnesium minerals, such as the pyroxenes, amphiboles, and olivine. Commonly found in metamorphic rocks, especially chlorite schists; also

with serpentine and dolomite. Occurs frequently as talc or talcose schist containing doubly terminated crystals of magnetite, dolomite, apatite, tourmaline, pyrite, and actinolite. Foliated talc is found at Greiner, Tyrol; various places in Switzerland, Italy, France, and Germany; Grafton and elsewhere, New Hampshire; St. Lawrence County, New York. The most important producing locality in the United States for talc and soapstone is in St. Lawrence County, New York, where talc occurs with limestone, and has been derived from tremolite and enstatite. Vermont is also an important producer of talc. Albermarle and Nelson counties, Virginia, Montgomery and Northhampton counties, Pennsylvania, and Phillipsburg, New Jersey also produce large quantities. Other important localities are in North Corolina, Georgia, Maryland, Rhode Island, Massachusetts, and California.

Talc and soapstone, cut into slabs or other shapes, are used for washtubs, sanitary appliances, laboratory tables and tanks, electrical switch boards, mantels, hearthstones, fire-bricks, foot warmers, slate pencils, and as crayon for marking iron, glass, and fabrics. Ground talc is used in toilet powders and soaps, for dressing skins and leather, as a lubricant, non-conductor of heat, and as "mineral pulp" as a filler in paint and paper.

**Sepiolite** (*Meerschaum*), $H_4Mg_2Si_3O_{10}$.

Monoclinic. Occurs only in compact nodular, earthy, or clayey masses.

Conchoidal to uneven fracture. Hardness 2 to 2.5. Impressed by the finger nail. Specific gravity 1 to 2. On account of its porosity it may float on water. Adheres to the tongue. Usually white, yellowish, or grayish in color. Dull luster.

$H_4Mg_2Si_3O_{10}$. Yields water when strongly ignited. Fuses with difficulty on thin edges to a white glass; some varieties first turn black. Gelatinizes with hydrochloric acid.

An alteration product of serpentine, magnesite, or impure opal containing considerable magnesium. It is found principally in nodular masses in serpentine or in secondary deposits, on the plains of Eskishehr, Asia Minor. Occurs in smaller quantities in Spain; the Grecian Archipelago; Morocco; Moravia; Utah; California; New Mexico.

Meerschaum is easily carved and worked on the lathe, takes an excellent polish, and is used extensively for pipe bowls and cigar tips. Claimed to be a building stone in Spain.

**Garnierite,** $H_2(Ni,Mg)SiO_4$.

Never found in crystals. Occurs commonly as rounded, pea-shaped masses with varnish-like surfaces; also compact, reniform or earthy; apparently amorphous.

Conchoidal or earthy fracture. Hardness 2 to 3. Specific gravity

2.3 to 2.8. Pale, apple, or emerald green in color. Dull to greasy luster. Greasy feel. Frequently adheres to the tongue. Streak, white to greenish.

$H_2(Ni,Mg)SiO_4$. Composition varies greatly. Infusible, decrepitates, and becomes magnetic. Yields water on ignition. Attacked by acids.

An alteration of olivine and serpentine rocks. Usually associated with olivine, serpentine, chromite, and talc. Occurs in serpentine at Noumea, New Caledonia; also found at Franckenstein, Silesia; Webster, North Carolina; Riddles, Douglas County, Oregon.

A valuable source of nickel.

**KAOLINITE** (*Kaolin, China Clay*), $H_4Al_2Si_2O_9$.

Monoclinic, prismatic class. Rarely in small scales with an hexagonal or orthorhombic outline. Generally in compact, friable, mealy, or clay-like masses.

Scales possess a basal cleavage. Earthy fracture. Hardness 1 to 2.5. Specific gravity 2.2 to 2.6. Compact masses are dull, scales pearly. White, yellowish, reddish, bluish, greenish, or brownish in color. Greasy feel. White to yellowish streak. Opaque to translucent. Usually adheres to the tongue and becomes plastic when moistened. Argillaceous odor when breathed upon.

$H_4Al_2Si_2O_9$. May contain some iron. Yields water on ignition. Infusible. Partially decomposed by hydrochloric acid. Occurs as a pseudomorph after many minerals.

Kaolinite is always a secondary mineral resulting from the action of post-volcanic, pneumatolytic, and hydrothermal processes upon rocks containing feldspar, nephelite, topaz, beryl, augite, scapolite, and other aluminous minerals. It may also result from ordinary weathering. Occurs in irregular deposits in kaolinized granites, porphyries, and gneisses. Also in secondary deposits, the result of transportation and deposition under water. These occurrences are often very pure. It is an important constituent of clay and soil. Common associates are feldspar, quartz, corundum, and diaspore. Some localities are: St. Yrieix, near Limoges, France; Cornwall and Devonshire, England; Meissen, Saxony. In the United States kaolin is mined at Newcastle and Wilmington, Delaware; also in Florida, North Carolina, Pennsylvania, Vermont, California, and Maryland.

Kaolinite is used in large quantities in the manufacture of chinaware, porcelain, tiles, and other refractory materials.

**NEPHELITE** (*Nepheline*), $(Na,K)_8Al_8Si_9O_{34}$.

Hexagonal, pyramidal class. Crystals are short prismatic or tabular. Commonly in compact masses or as disseminated grains.

Imperfect prismatic and basal cleavages. Conchoidal to uneven

fracture. Hardness 5 to 6. Specific gravity 2.55 to 2.65. Colorless, white, yellowish, greenish, gray, or reddish. Greasy luster on cleavages, otherwise vitreous. Transparent to opaque.

There are two varieties:

*Nephelite Proper.*—This includes the light colored, glassy occurrences showing in many instances a definite crystal outline. Common in the more recent eruptive rocks. Transparent to translucent.

*Elaeolite.*—This is a massive or granular variety and rarely shows a definite outline. Gray or more highly colored—green, red, brown, or blue. Cloudy or opaque. Greasy luster. Common in the older plutonic rocks, such as syenites, phonolites, and basalts.

$(Na,K)_8Al_8Si_9O_{34}$. Composition varies greatly. Formula is sometimes given as $NaAlSiO_4$, the composition of synthetic soda-nephelite. Potassium is usually present, also small amounts of calcium, lithium, and chlorine. Fuses easily to a colorless glass. Gelatinizes with hydrochloric acid, yielding on evaporation cubes of NaCl. Alters readily to hydronephelite, sodalite, muscovite, cancrinite, analcite, kaolinite, or garnet. Pseudomorphous after leucite.

Nephelite is commonly associated with feldspar, cancrinite, biotite, sodalite, corundum, and zircon; but not with primary quartz. Some localities are: Mount Vesuvius; Katzenbuckel, Baden; Laacher See, Rhenish Prussia; Southern Norway; Ural Mountains; Brazil; Ontario, Canada; Litchfield, Maine; Cripple Creek, Colorado; Magnet Cove, Arkansas; Salem, Massachusetts.

Nephelite is of no importance commercially.

**Cancrinite, $H_6(Na_2,Ca)_4(NaCO_3)_2Al_8Si_9O_{36}$.**

Hexagonal, dihexagonal bipyramidal class. Crystals are columnar or prismatic, but rare. Usually in compact, lamellar, columnar, or disseminated masses.

Perfect prismatic cleavage. Uneven fracture. Hardness 5 to 6. Specific gravity 2.45. Generally colored—lemon to brownish yellow, reddish, green; sometimes gray, white, or colorless. Pearly luster on cleavages, elsewhere vitreous to greasy. Transparent to translucent. Fuses easily with intumescence to a white blebby glass. Upon ignition turns white and yields water. Effervesces with hydrochloric acid and gelatinizes on heating.

Commonly associated with sodalite, nephelite, biotite, feldspar, titanite, and apatite. May be a primary constituent of igneous rocks, although in most cases it is secondary, resulting from the alteration of nephelite. Occurs in nephelite syenites at Barkevik, Norway; Miask, Ural Mountains; Finland; Sweden; Hungary; province of Quebec, Canada; Litchfield, Maine.

Cancrinite is of no importance commercially.

**Sodalite, $Na_4Al_2(AlCl)(SiO_4)_3$.**

Cubic, hextetrahedral class. Crystals are not common; when observed usually rhombic dodecahedrons. Generally in compact, cleavage, nodular, or disseminaed masses.

Distinct dodecahedral cleavage. Uneven to conchoidal fracture. Hardness 5 to 6. Specific gravity 2.2 to 2.4. Vitreous luster on crystal faces, greasy on cleavages. Usually blue in color; also white, green, reddish, or gray. Transparent to opaque. Colored varieties turn white when heated. Fuses with intumescence to a colorless glass. NaCl may be extracted by digesting the finely powdered mineral with water. Gelatinizes with hydrochloric acid.

Commonly associated with nephelite, cancrinite, leucite, feldspar, and zircon; but not with quartz. Occurs at Miask, Ural Mountains; Mount Vesuvius; Norway; provinces of Quebec and Ontario, Canada; Litchfield, Maine; Montana.

Sodalite is of no importance commercially.

**Lazurite** (*Lapis-Lazuli, Native Ultramarine*) **$(Na_2,Ca)_2Al_2[Al(NaSO_4,NaS_3,Cl)](SiO_4)_3$.**

Cubic. Crystals are rare, either dodecahedral or cubic in habit. Usually as irregular grains, or in masses containing disseminated pyrite (Fig. 617).

Fig. 617.—Lazurite (lapis lazuli). Persia.

Uneven fracture. Hardness 5 to 5.5. Specific gravity 2.4. Vitreous to greasy luster. Deep to azure blue in color, sometimes violet to greenish blue. Opaque to translucent. Fuses easily to a white blebby glass. Gelatinizes with hydrochloric acid, loses color, and evolves an odor of hydrogen sulphide.

Lazurite is a contact mineral and occurs in crystalline limestones. The principal localities are: Afghanistan; southern end of Lake Baikal, Siberia; Ovalle, Chile; Cascade Canyon, San Bernardino County, California.

Lazurite is highly valued for ornaments, mosaics, and vases. It was formerly used as a pigment in oil painting.

**Ilmenite** (*Menaccanite, Titanic Iron Ore*), **$FeTiO_3$.**

Hexagonal, trigonal rhombohedral class. Crystals are tabular or rhombohedral in habit and resemble those of hematite. Occasionally rhombohedrons of the second and third orders are present. Generally in compact or granular masses, also in thin plates or disseminated grains, or as pebbles or sand.

No cleavage, but basal and rhombohedral partings. Conchoidal to uneven fracture. Hardness 5 to 6. Specific gravity 4.3 to 5.5. Iron to brownish black in color. Black to brownish red streak. Metallic

to submetallic luster. Opaque; thin plates are brown in transmitted light. Slightly magnetic, greatly increased by heating.

$FeTiO_3$. Magnesium or manganese may replace some of the iron. Infusible. Yields a blue or violet solution after fusion with sodium carbonate and subsequent boiling with hydrochloric acid and tin foil.

As an accessory mineral it is common in many igneous and metamorphic rocks, such as, granite, syenite, diorite, diabase, gneiss, and mica schist. Also found in large quantities in black sands. Common associates are hematite, magnetite, apatite, serpentine, titanite, rutile, and quartz. Some localities are: Kragerö, Snarum, and elsewhere, Norway; various places in Sweden; St. Gothard district and Binnenthal, Switzerland; province of Quebec, Canada; Orange County, New York; Magnet Cove, Arkansas.

It is used in the preparation of linings for puddling furnaces and in making ferro-titanium. On account of the difficulty in reducing it, ilmenite is not used to any extent as an ore of iron.

### Pyroxene Group

The members of the pyroxene group are important rock minerals. They consist of metasilicates of calcium, magnesium, iron, aluminum, sodium, lithium, manganese, and zinc, corresponding to the general formula $M''_2(SiO_3)_2$. Although these minerals crystallize in three different systems—orthorhombic, monoclinic, and triclinic—they are all characterized by prism angles and cleavages of about 87° and 93°. The orthorhombic pyroxenes generally contain no calcium and little or no aluminum. The monoclinic members usually have considerable calcium and may, or may not, contain aluminum and the alkalies. In the triclinic series manganese is an important constituent.

The following important pyroxenes will be described:

| | | |
|---|---|---|
| Enstatite, Bronzite, Hypersthene | $(Mg,Fe)_2(SiO_3)_2$ | Orthorhombic |
| Diopside | $CaMg(SiO_3)_2$ | Monoclinic |
| Wollastonite | $Ca_2(SiO_3)_2$ | Monoclinic |
| Augite | $(Mg,Fe)Ca(SiO_3)(SiO_3)$<br>$(Mg,Fe)Al(AlO_3)(SiO_3)$<br>$(Mg,Fe)Fe(FeO_3)(SiO_3)$ | Monoclinic |
| Pectolite | $(Ca,Na_2)_2(SiO_3)_2$ | Monoclinic |
| Spodumene | $LiAl(SiO_3)_2$ | Monoclinic |
| Rhodonite | $Mn_2(SiO_3)_2$ | Triclinic |

The pyroxenes are rather closely related, chemically and crystallographically, to the minerals of the amphibole group. This relationship will be discussed on page 310.

**ENSTATITE,** *Bronzite, Hypersthene* $(Mg,Fe)_2(SiO_3)_2$.

Orthorhombic, bipyramidal class. Rarely found in distinct crystals, usually in fibrous, lamellar, columnar, or compact masses. Hypersthene occurs frequently in cleavable aggregates.

Prismatic and pinacoidal cleavages. Hardness 5 to 6. Specific gravity 3.1 to 3.5. Translucent to opaque.

*Enstatite.*—Grayish white, greenish, or brownish in color. Vitreous to pearly luster. Contains little or no iron.

*Bronzite.*—Darker in color than enstatite, usually brown, yellowish, or green. Pronounced pinacoidal parting, producing fibrous or irregular wavy surfaces with a chatoyant bronzy luster. Contains from 5 to 16 per cent. of iron.

*Hypersthene.*—Black, brownish black, or green in color. Pearly to metalloidal luster. Often shows a copper red iridescence on the macropinacoid. Contains more iron than magnesium.

These minerals occur commonly in basic igneous rocks such as pyroxenite, peridotite, norite, and gabbro. The most frequent associates are

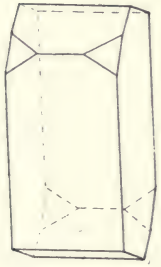


FIG. 618.

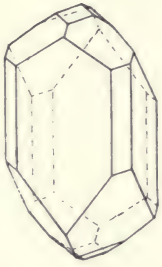


FIG. 619.

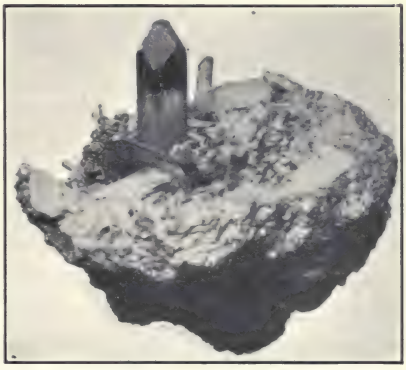


FIG. 620.—Diopside with zonal distribution of color. Ala, Italy.

olivine, chondrodite, serpentine, talc, labradorite, hornblende, pyrrhotite, and magnetite. Some localities are: Norway; Austria; Bavaria; Kimberley, South Africa; St. Paul's Island, off the coast of Labrador; Laacher See, Rhenish Prussia; Greenland; Scotland; along the Hudson River and in the Adirondack Mountains, New York.

Hypersthene showing an iridescence and metalloidal luster is sometimes used in jewelry.

**DIOPSIDE, $CaMg(SiO_3)_2$.**

Monoclinic, prismatic class. Crystals are generally short and thick, and nearly square or octagonal in cross-section, the faces of the unit prism intersecting at angles of 87° and 93°. Striations parallel to the basal pinacoid are frequently observed on the faces of the vertical zone. Common forms are the three pinacoids, unit prism, positive and negative hemi-pyramids, and the positive hemiorthodome (Figs. 618, 619, and 620). Occurs also in compact, broad columnar, granular, lamellar, or fibrous masses.

Prismatic cleavage and basal parting are conspicuous. Hardness 5 to 6. Specific gravity 3.2 to 3.3. Uneven to conchoidal fracture. Vitreous, resinous, or dull luster; sometimes inclining to pearly on the basal parting. Generally light to dark green in color; also colorless, gray, yellow, and rarely blue. Zonal distribution of color not uncommon (Fig. 620). White to greenish streak. Transparent to opaque.

$CaMg(SiO_3)_2$. Usually contains up to 5 per cent. of FeO. *Diallage* is a thin foliated, or lamellar variety, containing from 8 to 16 per cent. of iron oxide, and greenish or brownish in color. Aluminum and manganese may also be present. More or less fusible to a dark colored or green glass. Not acted upon by the common acids. Alters to serpentine, talc, chlorite, and limonite.

Occurs in granite, gabbro, basalt, pyroxenite, and peridotite; also in crystalline schists and as a contact mineral in limestone and dolomite. Common associates are vesuvianite, tremolite, garnet, scapolite, spinel, apatite, titanite, phlogopite, amphibole, tourmaline, and the feldspars. Found at various places in Tyrol; Zermatt, Switzerland; Pargas, Finland; Sweden; Lanark and Hastings counties, Ontario; Lewis and St. Lawrence counties, New York.

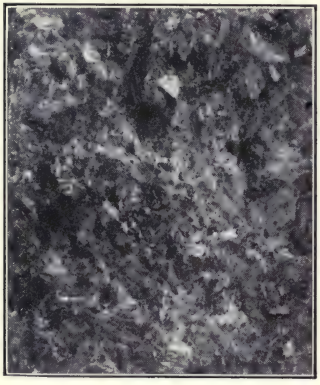


FIG. 621.—Wollastonite Bucks County, Pennsylvania.

Clear and transparent varieties are sometimes used for gem purposes.

**Wollastonite** (*Tabular Spar*), $Ca_2(SiO_3)_2$.

Monoclinic, prismatic class. Crystals are usually elongated parallel to the *b* axis and tabular in habit. Most commonly observed in cleavable (Fig. 621), fibrous, granular, and compact masses. The fibers may have a parallel or divergent structure.

Basal and orthopinacoidal cleavages. Uneven fracture. Hardness 4 to 5. Specific gravity 2.8 to 2.9. Usually white, colorless, or gray; also yellowish, reddish, or brownish. Vitreous to silky luster. Transparent to translucent.

$Ca_2(SiO_3)_2$. Generally mixed with calcite, and hence effervesces with acid. Fusible on the thin edges. Decomposes with hydrochloric acid with separation of silica.

Wollastonite is a typical contact metamorphic mineral and is generally associated with garnet, diopside, vesuvianite, tremolite, graphite, epidote, and calcite. It is found in granular limestone, granite, and basalt. Some localities are: the Island of Elba; Norway; Mount Vesuvius; Hungary; Grenville, Quebec; North Burgess and elsewhere, Ontario; Lewis and Warren counties, New York; California.

**AUGITE.**

Monoclinic, prismatic class. Crystal are short, prismatic, or thick columnar with a prism angle of 87°, yielding a pseudotetragonal outline. The most usual combination consists of the ortho- (*a*) and clinopinacoids (*b*), unit prism (*m*), positive unit hemi-pyramid (*o*) and negative hemi-orthodome (*t*) (Figs. 622 and 623). Sometimes occurs as contact twins, twinned parallel to the orthopinacoid (Fig. 624) or as penetration twins

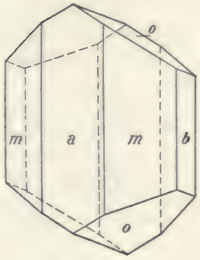



FIG. 622.

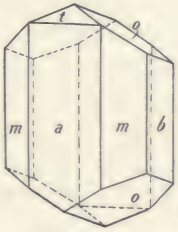



FIG. 623.

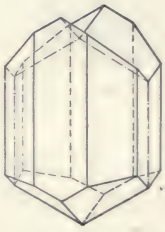


FIG. 624.

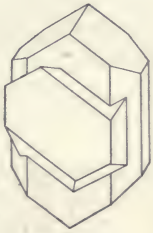


FIG. 625.

in which the clinohemipyramid is the twinning plane (Fig. 625). It is also observed in compact and disseminated grains and granular aggregates; rarely fibrous.

Prismatic cleavage. Conchoidal to uneven fracture. Hardness 5 to 6. Specific gravity 3.2 to 3.6, varying with the composition. Commonly black or greenish black in color, also leek green. Grayish green streak. Usually opaque, but may be translucent. Vitreous to dull.

Chemically, augite is considered an isomorphous mixture of (Mg,Fe)-$Ca(SiO_3)(SiO_3)$, $(Mg,Fe)Al(AlO_3)(SiO_3)$, and $(Mg,Fe)Fe(FeO_3)(SiO_3)$. Sodium and titanium are sometimes present. Fuses and often forms a magnetic glass. Slightly acted upon by acids. Alters to a fibrous hornblende having the form of augite, termed *uralite*, and also to serpentine.

Augite is a common rock mineral, and often occurs in disseminated crystals as an essential or accessory constituent of basalt, melaphyre, diabase, gabbro, tuff, and volcanic sand and ashes. Also occurs in crystalline schists and limestones, and is commonly the result of contact metamorphism. Some notable localities are: Fassathal, Tyrol; Mount Vesuvius; Mount Aetna; Kaiserstuhl, Baden; Bohemia; Norway; Finland; Thetford, Vermont; Amherst County, Virginia.

**Pectolite $(Ca,Na_2)_2(SiO_3)_2$.**

Monoclinic, prismatic class. Crystals are commonly tabular, but rare. Generally consists of aggregates of divergent fibers or acicular crystals, sometimes of considerable length and with sharp ends (Fig. 626).

Basal and orthopinacoidal cleavages. Uneven fracture. Hardness 4 to 5. Specific gravity 2.7 to 2.8. Colorless, white, or grayish white. Translucent to opaque. Vitreous pearly to silky luster.

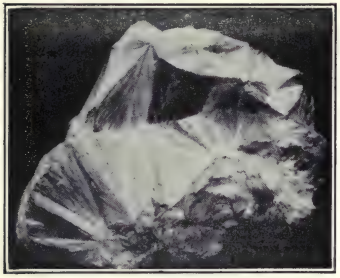


Fig. 626.—Pectolite. Paterson, New Jersey.

$(Ca,Na_2)_2(SiO_3)_2$. Usually contains about 10 per cent. of sodium oxide. Manganese is sometimes present. Yields water in a closed tube. Decomposed by hydrochloric acid with the separation of silica. Sometimes phosphoresces when crushed in the dark.

Occurs in fissures and cavities in basic igneous and metamorphic rocks. Commonly associated with the zeolites, datolite, and calcite. Some localities are: Fassathal and Monzoni, Tyrol, Scotland; Thunder Bay, Ontario; Bergen Hill, Paterson, and vicinity, New Jersey; Isle Royale, Michigan.

**SPODUMENE,** *Hiddenite, Kunzite,* $LiAl(SiO_3)_2$.

Monoclinic, prismatic class. Long, columnar crystals with the unit prism predominating; also tabular, and frequently with vertical striations and furrows (Fig. 627). Often very large, several crystals from the Etta mine, near Keystone, South Dakota, having measured over 30 feet in length and from 2½ to 6 feet in width. Occurs more commonly in cleavable masses and broad columnar aggregates.

Fig. 627.—Spodumene. Norwich, Massachusetts.

Perfect prismatic cleavage; also very easy parting parallel to the orthopinacoid. Uneven to splintery fracture. Hardness 6 to 7. Specific gravity 3.1 to 3.2. White, grayish, green, pink, and purple. Vitreous to pearly luster. Transparent to opaque. *Hiddenite* is a clear yellow to emerald green variety from Stony Point, Alexander County, North Carolina. A transparent lilac pink variety from Pala, San Diego County, California, is called *kunzite.* This variety phosphoresces with an orange pink light when exposed to electric discharges, the X-rays, ultra-violet light, or to radium emanations.

$LiAl(SiO_3)_2$. Usually contains some sodium, iron, and calcium. Fuses easily, turns white, intumesces, and colors the flame purple red. Insoluble in acids. Alters to albite, muscovite, and quartz.

Occurs in pegmatite veins with tourmaline, beryl, garnet, lepidolite, feldspar, mica, and quartz as the principal associates. Some localities are: Sweden; Tyrol; Ireland; Windham, Maine; Sterling, Chester, and Goshen, Massachusetts; Branchville, Connecticut; Stony Point,

Alexander County, North Carolina; Etta mine, Pennington County, South Dakota; Pala, San Diego County, California.

Hiddenite and kunzite are used for gem purposes. The output of the Etta mine, near Keystone, South Dakota, furnishes an important source of lithium compounds, some of which are used in the manufacture of red fire and for medicinal purposes.

**RHODONITE,** *Fowlerite*, $Mn_2(SiO_3)_2$.

Triclinic, pinacoidal class. Crystals are usually tabular or prismatic, comparatively large and with rounded edges, but not very common (Fig. 628). Occurs generally in fine grained, cleavable, or compact masses; also in disseminated grains.

Prismatic and basal cleavages. Conchoidal to uneven fracture. Hardness 5 to 6. Specific gravity 3.4 to 3.7. Rose-red, pink, yellowish, greenish, or brownish in color; often black externally. Vitreous to pearly luster. Transparent to opaque.

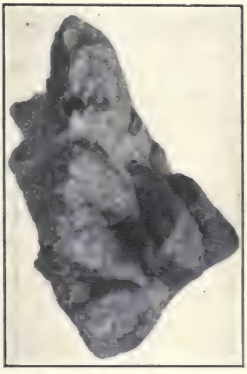


FIG. 628.—Rhodonite. Franklin Furnace, New Jersey.

$Mn_2(SiO_3)_2$. Commonly contains some calcium and iron. *Fowlerite* is a zinciferous variety from the Franklin Furnace district, New Jersey. Fuses easily to a brownish or black glass. Slightly acted upon by acids, although varieties containing an admixture of calcite will effervesce.

Occurs with calcite, rhodochrosite, tetrahedrite, franklinite, willemite, zincite, quartz, and iron ores. Some localities are: the Hartz Mountains; Hungary; Italy; Sweden; Ural Mountains; Peru; Cummington, Massachusetts; Franklin Furnace, New Jersey; Butte, Montana.

Sometimes used for gem and ornamental purposes.

## Amphibole Group

The members of the amphibole group are closely related to the pyroxenes, being important rock minerals and metasilicates of magnesium, aluminum, iron, calcium, sodium, and potassium which possess the general formula $M''_4(SiO_3)_4$. Like the pyroxenes, these minerals also crystallize in the orthorhombic, monoclinic, and triclinic systems, but only the following monoclinic amphiboles are sufficiently important to warrant description:

| | |
|---|---|
| Tremolite | $CaMg_3(SiO_3)_4$ |
| Actinolite | $Ca(Mg,Fe)_3(SiO_3)_4$ |
| Hornblende | $Ca(Mg,Fe)_3(SiO_3)_2(SiO_3)_2$<br>$Al_2(Mg,Fe)_3(AlO_3)_2(SiO_3)_2$<br>$Fe_2(Mg,Fe)_3(FeO_3)_2(SiO_3)_2$ |

The principal differences between the members of the pyroxene and amphibole groups may be tabulated as follows:

| | Pyroxenes | Amphiboles |
|---|---|---|
| Crystals | Short, prismatic, complex, commonly four- or eight-sided. | Long prismatic, simple commonly six-sided. |
| Prism angles | 87° and 93° | 56° and 124° |
| Cleavages | Prismatic, nearly 90° bladed. | Prismatic, nearly 120°, more distinct. |
| Masses | Lamellar or granular | Columnar or fibrous |
| Specific gravity | Higher | |
| Chemical composition | Alter to amphibole | Magnesium and the alkalies are more prominent. |
| Occurrence | Common in more basic rocks. | Common in more acid rocks. |

**Tremolite, $CaMg_3(SiO_3)_4$.**

Monoclinic, prismatic class. Crystals are bladed, either long or short, but generally without terminal faces (Fig. 629). Occurs also

FIG. 629.—Tremolite. Haliburton, Ontario.

in fibrous and asbestiform aggregates, and in compact columnar or granular masses.

Perfect prismatic cleavage, at angles of 56° and 124°. Hardness 5 to 6. Specific gravity 2.9 to 3.1. Generally white, gray, greenish, or yellowish in color. *Hexagonite* is an amethystine to lavender variety, due to a small amount of manganese. Vitreous to silky luster. Transparent to opaque.

$CaMg_3(SiO_3)_4$. Contains little or no iron. Not acted upon by acids. Fuses with difficulty. Alters to talc.

Tremolite is a contact metamorphic mineral, and occurs in granular limestones and dolomites, and schists. Found in the St. Gotthard district, Switzerland; various places in Sweden and Hungary; Lee, Massachusetts; Easton, Pennsylvania; Edenville, Orange County, and Edwards, St. Lawrence County, New York; Pontiac County, Quebec; Renfrew and Lanark counties, Ontario.

**Asbestos**

Under this term are included fibrous varieties of tremolite, actinolite, and other non-aluminous amphiboles. The fibers are sometimes long, parallel, flexible, and easily separated by the fingers. Amphibole asbestos is commonly called *long fibered asbestos*, while serpentine asbestos, see page 298, is termed *short fibered*. The heat resisting property of the amphibole asbestos is about the same as that of the chrysotile asbestos, but the non-conductivity of heat and strength of fiber are less. It is also not as suitable for spinning as the short fibered asbestos. Hence, serpentine or chrysotile asbestos gives the better results. Amphibole asbestos occurs at Sall Mountain, Georgia, and in Lewis County, Idaho. For the uses of asbestos, see page 299.

**Actinolite, $Ca(Mg,Fe)_3(SiO_3)_4$.**

Monoclinic, prismatic class. Long or short bladed crystals, but generally without terminal faces (Fig. 630). Occurs usually in divergent

FIG. 630.—Actinolite (dark) in talc. Greiner, Tyrol.

or irregular columnar, fibrous, or asbestiform aggregates; also in compact granular masses. *Nephrite* is a compact variety and is included in the general term *jade*.[1]

Perfect prismatic cleavage, at angles of about 56°and 124°. Hardness 5 to 6. Specific gravity 2.9 to 3.2. Usually green in color. Vitreous to silky luster. Transparent to opaque.

$Ca(Mg,Fe)_3(SiO_3)_4$. Usually contains considerable iron, and small amounts of aluminum and sodium. Fuses to a gray enamel. Slightly acted upon by acids. Alters to talc, chlorite, epidote, or to an aggregate of serpentine and calcite.

Actinolite occurs in crystalline schists; sometimes in such quantities that the rock may be termed *actinolite schist*. It is often the result of contact metamorphism. Some localities are: Greiner, Zillerthal, Tyrol; Norway; Zöblitz, Saxony; Iyo, Japan; Brome County, Quebec; Bare Hills, Maryland; Franklin Furnace, New Jersey; Delaware and Chester

[1] Jade includes certain varieties of actinolite and jadeite, a compact pyroxene with the formula $NaAl(SiO_3)_2$.

counties, Pennsylvania; Lee and Chester, Massachusetts; Windham, Vermont.

**HORNBLENDE.**

Monoclinic, prismatic class. Prismatic crystals with a pseudo-hexagonal outline and rhombohedral terminations are common. The prism angles are 56° and 124°. The common forms are the unit prism (*m*), clinopinacoid (*b*), clinodome (*d*), and positive unit hemiorthodome

FIG. 631.

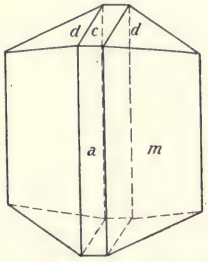



FIG. 632.

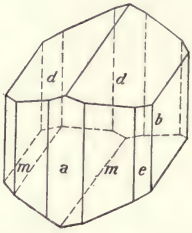



FIG. 633.

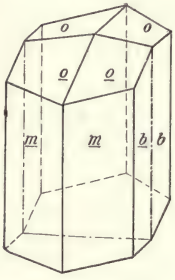



FIG. 634.

(*q*) (Figs. 631, 632, 633, 635, and 636). Sometimes twinned parallel to orthopinacoid (Fig. 634). Occurs also in bladed, fibrous, columnar, granular, or compact masses.

Perfect prismatic cleavage. Hardness 5 to 6. Specific gravity 2.9 to 3.3. Usually dark green, brown, or black in color; grayish green to grayish brown streak. Vitreous to silky luster. May be transparent, but generally only translucent to opaque.

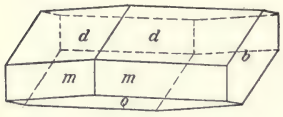



FIG. 635.

FIG. 636.—Hornblende. Bilin, Bohemia.

Chemically, hornblende is an isomorphous mixture of $Ca(Mg,Fe)_3(SiO_3)_2(SiO_3)_2$, $Al_2(Mg,Fe)_2(AlO_3)_2(SiO_3)_2$, and $Fe(Mg,Fe)_2(FeO_3)_2(SiO_3)_2$. The composition is strikingly similar to that of augite, see page 307. Some varieties contain small amounts of the alkalies and titanium. A small amount of water is usually present, which tends to distinguish hornblende from augite. Alters to chlorite, epidote, calcite, siderite, limonite, and quartz. *Uralite* is pyroxene altered to amphibole with the form of the original mineral but the cleavage of amphibole. Pyroxene commonly alters in this way and the process is termed *uralization*.

Hornblende is commonly associated with quartz, feldspar, pyroxene, chlorite, and calcite. It is an essential or accessory constituent of many plutonic rocks such as granite, syenite, and diorite; also of hornblende schist, andesite, phonolite, gabbro, and crystalline limestones.

Some of the more important localities are: Mount Vesuvius; Bilin, Bohemia; Pargas, Finland; Renfrew County, Ontario; Russel, Pierrepont, and DeKalb, New York; Hawley, Massachusetts; Franconia, New Hampshire; Franklin Furnace, New Jersey.

---

**LEUCITE, $K_2Al_2Si_4O_{12}$.**

Dimorphous, orthorhombic and cubic. At ordinary temperatures crystals are pseudocubic, in that they show what is apparently a tetragonal trisoctahedron; at times also the cube and rhombic dodecahedron. Optically, the crystals consist of orthorhombic twin lamellæ, which can sometimes be recognized by the striations on the faces. Heated to a temperature of 500°C., the lamellæ disappear and the crystals become isotropic and truly cubic. Generally found in well developed and disseminated crystals (Fig. 637); also in rounded grains.

Fig. 637.—Leucite (light) in basalt. Tavolato, Italy.

Conchoidal fracture. Hardness 5.5 to 6. Specific gravity 2.5. White, gray, yellowish, or reddish in color. Vitreous to greasy luster. Translucent, rarely transparent.

$K_2Al_2Si_4O_{12}$. Sodium may replace some of the potassium. Infusible. Alters to analcite and kaolin.

Leucite occurs usually in eruptive rocks. The principal associates are sanidine, augite, nephelite, and olivine. Some localities are: Mount Vesuvius; Laacher See, Rhenish Prussia; Kaiserstuhl, Baden; Saxony; Brazil; Leucite Hills, Wyoming; Magnet Cave, Arkansas.

At present leucite is of no importance commercially.

**BERYL, $Be_3Al_2Si_6O_{18}$.**

Hexagonal, dihexagonal bipyramidal class. Crystals are usually long prismatic and very simple (Fig. 638 and 639). Rarely tabular. Sometimes highly modified, showing prisms and forms. Crystals are frequently striated vertically and may be very large. Occurs also in columnar, granular, and compact masses, and in rounded grains and masses in secondary deposits.

Distinct basal cleavage. Conchoidal to uneven fracture. Hardness 7.5 to 8; is sometimes substituted for topaz in the scale of hardness.

Specific gravity 2.6 to 2.8. Various shades of green, blue, yellow, and reddish in color; sometimes mottled. Vitreous luster. Transparent to translucent.

There are five important varieties of beryl:

(1) *Emerald.*—Emerald green in color. Transparent. Highly prized as a precious stone.

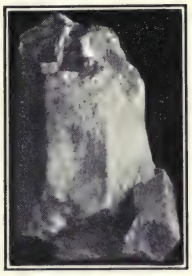


FIG. 638.—Beryl. Auburn, Maine.

FIG. 639.

(2) *Aquamarine.*—Usually blue to sea green in color. Transparent. Used as a gem, but not as valuable as the emerald.

(3) *Yellow or Golden Beryl.*—Beautiful golden yellow in color. Transparent. An attractive gem stone.

(4) *Morganite.*—Pale pink to rose red in color. Transparent. Used as a gem.

FIG. 640.—Beryl in quartz. Acworth, New Hampshire.

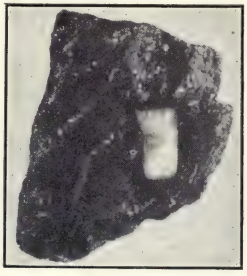


FIG. 641.—Beryl: Variety, emerald. Bogota, Columbia.

(5) *Common Beryl.*—Generally green, yellowish, or grayish white in color. Often mottled. Crystals are sometimes extremely large, being measured in feet and weighing as much as 1,500 kilograms (Grafton, New Hampshire).

$Be_3Al_2(SiO_3)_6$. Beryllium may be partially replaced by varying amounts of calcium, iron, potassium, sodium, and cæsium. Fuses with great difficulty, turning white and cloudy. Insoluble in acids. Alters to mica and kaolin.

Commonly found in pegmatite veins, gneiss, mica schist, clay slate, limestone, or in secondary deposits. The common associates are quartz (Fig. 640), feldspar, mica, topaz, tourmaline, cassiterite, chrysoberyl, garnet, zircon, and corundum. Emeralds of good quality occur in limestone at Muzo, Columbia (Fig. 641), district of Ekaterinburg, Ural Mountains; Tyrol; Upper Egypt; Alexander County, North Carolina; Chaffee County, Colorado. Morganite is found on the Island of Madagascar and in San Diego County, California. Aquamarine and other gem beryls occur on the Island of Elba; Ireland; Mursinka, Ural Mountains; Mitchell County, North Carolina; in secondary deposits in Brazil, Ceylon, and India. Common beryl occurs in very large crystals at Grafton and Acworth, New Hampshire; Royalston, Massachusetts; Paris and Stoneham, Maine; Haddam and Litchfield, Connecticut; Pennsylvania; Black Hills, South Dakota.

Used for gem purposes and as a source of beryllium and its compounds.

## Feldspar Group

The feldspars constitute the most abundant group of minerals. They are very important rock minerals and, according to Clarke, make up about 60 per cent. of the igneous rocks. Their chemical composition is very similar and may be expressed in general by the formulas $M'AlSi_3O_8$ or $M''AlSi_2O_8$, in which the metal may be potassium, sodium, calcium, or more rarely barium. The feldspars crystallize in the monoclinic and triclinic systems, but many of their physical properties are strikingly similar. The prism angles are about 120°. Hardness 6 to 6.5. Specific gravity 2.55 to 2.75. The color is usually white or gray, but may also be reddish, yellow, or greenish. All feldspars possess good cleavages in two directions, that is, parallel to basal and clino- or brachypinacoids. In the case of orthoclase these cleavages make an angle of 90°, but in the case of the triclinic members they are inclined, their angles differing slightly from 90°.

The feldspars are important economic minerals and 132, 681 short tons were produced in the United States in 1916; 82 per cent. of the output was consumed in the ceramic industries. The chief producing states are North Carolina, Maine, Maryland, New York, and Connecticut.

The following feldspars will be described:

| | | |
|---|---|---|
| Orthoclase, | $KAlSi_3O_8$ | Monoclinic |
| Microcline, | $KalSi_3O_8$ | Triclinic |
| | Plagioclases | |
| Albite, | $NaAlSi_3O_8$(Ab) | Triclinic |
| Labradorite, | $Ab_1An_1$ to $Ab_1An_3$ | Triclinic |
| Anorthite, | $CaAl_2Si_2O_8$(An) | Triclinic |

Igneous rocks are commonly classified according to the kind of feldspar they contain.

**ORTHOCLASE** (*Potash Feldspar*, *Feldspar*), $KAlSi_3O_8$.

Monoclinic, prismatic class. Well developed crystals are common, the habit being usually prismatic parallel to the *c* axis (Fig. 642), tabular parallel to the clinopinacoid, or square columnar and elongated parallel to the *a* axis (Fig. 643). In the latter case the basal and clinopinacoids

FIG. 642.—Orthoclase. Lincoln County, Nevada.

FIG. 643.—Orthoclase: Variety, sanidine. Fort Bayard, New Mexico.

FIGS. 644 and 645.—Orthoclase (left and right Karlsbad twins). Fort Bayard, New Mexico.

are about equally developed. The unit prism, positive hemi-orthodomes, a clinodome, and the basal and clinopinacoids are the forms most frequently observed. Crystals are sometimes highly modified and may be quite large. Twinning is frequently observed according to three laws.

(1) *Karlsbad Law.*—The orthopinacoid acts as the twinning plane or the crystallographic *c* axis may be considered the twinning axis. Irregular penetration twins are common (Figs. 644 and 645).

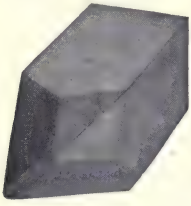


FIG. 646.

FIG. 647.

(2) *Baveno Law.*—The clinodome ($\infty a : b : 2c$) is the twinning plane. Nearly square or columnar contact twins are most common (Fig. 646).

(3) *Manebach Law.*—This law yields contact twins with the basal pinacoid acting as the twinning and composition plane (Fig. 647). This law is not as common as the first two.

Aside from occurring in crystals, orthoclase is found in cleavable, compact, or granular masses, and in irregular disseminated grains. Some massive orthoclase resembles jasper or flint.

Perfect basal and good clinopinacoidal cleavages, making an angle of 90° (Fig. 648). Conchoidal to uneven fracture. Hardness 6. Specific gravity 2.5 to 2.6. Usually colorless, white, gray, or reddish, or yellowish; more rarely greenish. Transparent to opaque. Vitreous to pearly luster.

FIG. 648.—Orthoclase showing rectangular cleavage.

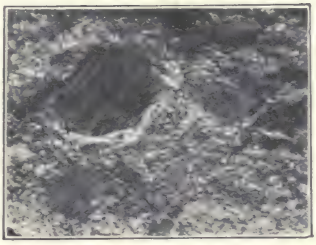


FIG. 649.—Orthoclase: Variety, sanidine, in trachyte. Drachenfels, Rhine Valley.

There are three important varieties:

(1) *Adularia.*—This variety occurs usually in white or colorless crystals, which may be transparent or slightly cloudy. It frequently possesses an excellent opalescence. It is then termed *moonstone* and is used for gem purposes. Usually found in cracks and veins in gneiss and mica schist.

(2) *Sanidine.*—Occurs in glassy, transparent or translucent crystals, and is sometimes called *glassy feldspar*. Generally colorless, white, or gray. Tabular and square habits and Karlsbad twins are very common. Characteristic of eruptive rocks, especially rhyolite, trachyte, and phonolite (Fig. 649).

FIG. 650.—Orthoclase intergrown with quartz (graphic granite). Bedford, N. Y. (*After Bastin.*)

(3) *Ordinary or Common Orthoclase.*—Generally more or less dull in color, yellowish, flesh red, dark red, or greenish. Occurs in well developed crystals and in cleavable or compact granular masses. Very common in granite, syenite, gneiss, and pegmatites.

$KAlSi_3O_8$. Often contains some sodium. Fuses with difficulty. Insoluble in acids. Alters to kaolinite, muscovite, and epidote. Occurs as a pseudomorph after analcite and leucite.

Orthoclase is a very common mineral. It is especially characteristic of such plutonic rocks as granite and syenite, and in pegmatite dikes cutting them. It is also an important constituent of certain eruptive and

metamorphic rocks, for example, rhyolite, trachyte, phonolite, porphyry, gneiss, and various schists. Not infrequently it occurs in some sandstones and conglomerates. The most common associates of orthoclase are muscovite, biotite, quartz (Fig. 650), tourmaline, the other feldspars, hornblende, apatite, zircon, and beryl. It occurs widely distributed and is frequently considered the most abundant of the silicate minerals. A few localities for excellent crystals are: the St. Gothard district, Switzerland; Mount Vesuvius; Karlsbad, Bohemia; Striegau, Silesia; Norway; Ceylon; Perth, Quebec; Bedford, Ontario; Paris, Maine; Acworth, New Hampshire; Haddam, Connecticut; St. Lawrence County, New York; Mount Antero, Chaffee County, Colorado. Massive varieties are found at Bedford, Ontario; Georgetown and Brunswick, Maine; Crown Point and elsewhere, New York; also in Pennsylvania, Maryland, Virginia, Minnesota, and Massachusetts.

The feldspar of commerce is principally orthoclase or microcline, or an intergrowth of both. It is used chiefly as a constituent of the glaze of porcelain, china, or enamel ware, and as a flux in the manufacture of emery and other abrasive wheels. Small quantities are also used in opalescent glass, artificial teeth, scouring soap, and paint fillers. Moonstone is used as a gem.

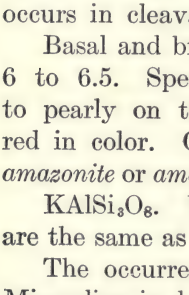


FIG. 651.—Microcline: Variety, Amazon stone. Pike's Peak, Colorado.

**MICROCLINE, $KAlSi_3O_8$.**

triclinic, pinacoidal class. Crystals resemble very closely those of orthoclase in habit (Fig. 651), angles, crystal forms, and twinning. The angle between the basal and brachypinacoids differs slightly from 90°, being about 90° 30′. Crystals are frequently large and although apparently simple individuals, they are in reality usually polysynthetic twins according to the ablite and pericline laws—see page 320—so characteristic of ablite and other triclinic feldspars. Accordingly basal sections of microcline show under the microscope a characteristic grating or gridiron structure. Also occurs in cleavable and compact granular masses.

Basal and brachypinacoidal cleavages. Uneven fracture. Hardness 6 to 6.5. Specific gravity 2.54 to 2.57. Vitreous luster, inclining to pearly on the basal pinacoid. White, yellowish, gray, green, or red in color. Green varieties—often bright verdigris green—are called *amazonite* or *amazonstone*. Transparent to translucent.

$KAlSi_3O_8$. Usually contains some sodium. The chemical properties are the same as for orthoclase.

The occurrence of microcline is very similar to that of orthoclase. Microcline is, however, not common in eruptive rocks. Smoky quartz and topaz are typical associates. Intergrowths with orthoclase, albite, and the other feldspars are common. Some localities are: Striegau,

Silesia; Arendal, Norway; Ural Mountains; Greenland; Pike's Peak district, Colorado.

Amazonstone is cut and polished for gem and ornamental purposes.

## Plagioclase Feldspars

These Feldspars are sometimes called the soda-lime feldspars. They crystallize in the triclinic system, forming an isomorphous series with albite and anorthite as the end members. The chemical composition of the various members of this series may be indicated as follows:—

Albite, $NaAlSi_3O_8$ ..... (Ab),
Olgioclase, Ab ..... $Ab_3An$,
Andesine, $Ab_3An$ ..... $Ab_1An_1$
Labradorite, $Ab_1An_1$ ..... $Ab_1An_3$
Bytownite, $Ab_1An_3$ ..... An,
Anthorite, $CaAl_2Si_2O_8$ ..... (An).

These feldspars possess good cleavages parallel to the basal and brachypinacoids, which are inclined to each other at angles of about 86°. This inclined or oblique cleavage serves to differentiate these feldspars, the *plagioclases*, from orthoclase which possesses a rectangular cleavage.

The following table shows clearly the progressive changes in the physical and chemical properties of the various members of this group.

| Name | Composition | Per cent. of Anorthite | $SiO_2$ | CaO | $Na_2O$ | $Al_2O_3$ | Specific Gravity | Extinction Angles | | Cleavage Angles |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Basalt | Brachy | |
| Albite | Ab | 0.0 | 68.6 | .... | 11.8 | 19.6 | 2.605 | 4½° | 19° | 86° 24′ |
| Oligoclase | $Ab_3An_1$ | 26.0 | 61.9 | 5.2 | 8.7 | 24.2 | 2.659 | 1° | 4½ | 86° 32′ |
| Andesine | $Ab_1An_1$ | 51.5 | 55.4 | 10.4 | 5.7 | 28.5 | 2.694 | −5° | −16° | 86° 14′ |
| Labradorite | $Ab_1An_3$ | 76.1 | 49.1 | 15.3 | 2.8 | 32.8 | 2.728 | −17½° | −29½° | 86° 4′ |
| Bytownite | An | 96.0 | 46.6 | 17.4 | 1.6 | 34.4 | 2.742 | −27½° | −33½° | — |
| Anorthite | | 100.0 | 43.0 | 20.1 | ... | 36.9 | 2.765 | −37° | −36° | 85° 50′ |

The intermediate members are important constituents of many igneous rocks and more common than either albite or anorthite. They are rarely well crystallized, but can usually be recognized by the striations on the basal pinacoid, due to multiple twinning according to the albite law. Only albite, labradorite, and anorthite will be described.

**ALBITE** (*Soda Feldspar*) $NaAlSi_3O_8$.

Triclinic, pinacoidal class. Crystals are usually not large and often similar in development to those of orthoclase (Figs. 652 and 653). They

may also be tabular and elongated parallel to the *b* axis (Fig. 656). Twins are very common, single individuals being rare. There are two important laws.

(1) *Albite Law.*—This involves the brachypinacoid acting as the twinning plane, and yields simple contact and repeated twins (Figs. 654 and 655). The polysynthetic twins according to this law show striations on the basal pinacoid which extend parallel to the edge between the basal and brachypinacoids.

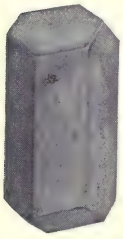


FIG. 652.

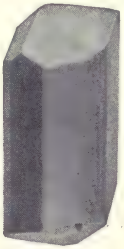


FIG. 653.

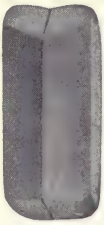


FIG. 654.

FIG. 655.

(2) *Pericline Law.*—The *b* axis acts as the twinning axis (Fig. 657). Contact and polysynthetic twins are observed, the latter being characterized by striations on the brachypinacoid.

Albite also occurs in lamellar and granular masses, the laminæ being often curved and divergent.

Perfect basal and brachypinacoidal cleavages, *inclined* at 86° 24′ Uneven fracture. Hardness 6 to 6.5. Specific gravity 2.6. Usually colorless or gray; rarely colored. Transparent to translucent. Some varieties show a bluish opalescence and are called *moonstone.*

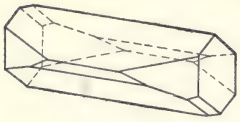


FIG. 656.

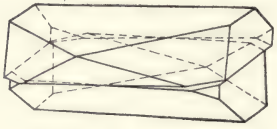


FIG. 657.

$NaAlSi_3O_8$. Generally contains some potassium and calcium. Fuses to a colorless or white glass. Colors the flame yellow. Not acted upon by acids.

As a rock mineral, albite is not as abundant as the other plagioclases. It occurs, nevertheless, in many gneisses and other crystalline schists, also in granite, diorite, trachyte, and other eruptive rocks; more rarely in limestone and dolomite. Frequently found in pegmatite veins, but also in cracks and crevices. Some of the associates of albite are chlorite, titanite, adularia, axinite, beryl, tourmaline, quartz, chrysoberyl, and

apatite. It occurs often intergrown with orthoclase or microcline, and is then known as *perthite* (Fig. 658).

Some important localities are: the St. Gothard district, Switzerland; various places in the Tyrol; Rauris, Salzburg; Dauphine, France; Ural Mountains; Paris, Maine; Haddam, and Branchville, Connecticut; Chesterfield, Massachusetts; Pike's Peak, Colorado; Amelia Court House, Virginia (Fig. 659).

Moonstone is often used for gem purposes.

FIG. 658.—Perthitic intergrowth of microcline and albite. Georgetown, Maine. (*After Bastin.*)

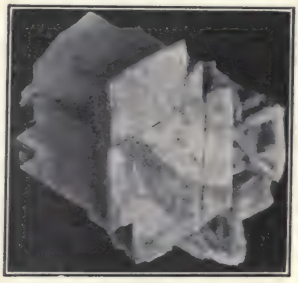


FIG. 659.—Albite. Amelia Court House, Virginia.

**LABRADORITE** (*Lime-soda Feldspar*), $Ab_1An_1$ to $Ab_1An_3$.

Triclinic, pinacoidal class. Well developed crystals are rare. In habit they are usually tabular to the brachypinacoid. The twinning is the same as for albite. Generally observed in cleavable, granular, or cryptocrystalline masses.

Perfect basal and brachypinacoidal cleavages, making an angle of 86°4′. Uneven fracture. Hardness 6 to 6.5. Specific gravity 2.7. Gray, brown, or greenish in color. Often shows a beautiful play of yellowish, bluish, greenish, or reddish colors on the brachypinacoid. This *labradorescence* is due to a fine lamellar structure or to microscopic inclusions, or to both. Translucent.

$Ab_1An_1$ to $Ab_1An_3$. Fuses to a colorless or white glass. Colors the flame yellow. Decomposed with difficulty by hydrochloric acid.

Occurs in basic igneous rocks, such as gabbro, norite, basalt, diabase, and andesite. Found on Mount Aetna; in Transylvania; Sweden; Greenland; varieties showing an excellent play of colors are common on the

coast of Labrador, also on the Isle of St. Paul; in the Adirondack Mountains, New York; Wichita Mountains, Arkansas; and elsewhere.

Varieties showing a good play of colors are used for ornamental and decorative purposes. They are sometimes termed *labrador spar.*

**Anorthite** (*Lime Feldspar*), $CaAl_2Si_2O_8$.

Triclinic, pinacoidal class. Crystals are usually prismatic parallel to the *c* axis, or tabular parallel to the basal pinacoid; often very complex. Twins occur according to the laws common on albite. Also observed in cleavable, compact, and lamellar masses.

Perfect basal and brachypinacoidal cleavages, inclined at an angle of 85° 50′. Conchoidal to uneven fracture. Hardness 6 to 6.5. Specific gravity 2.7 to 2.8. Commonly white, colorless, or grayish; more rarely bluish, yellowish, or reddish. Vitreous luster, inclining to pearly on the cleavages. Transparent to translucent.

$CaAl_2Si_2O_8$. Usually contains small amounts of sodium and at times of potassium, magnesium, and iron. Fuses with difficulty to a colorless glass. Decomposed by hydrochloric acid with a separation of gelatinous silica.

Anorthite occurs as an important constituent of basic igneous rocks, such as gabbros, diorites, and basalts; also as a contact mineral and in meteorites. Excellent crystals are found on Mount Vesuvius; Island of Miyake, Japan; Iceland; Monzoni district, Tyrol; Transylvania; Ural Mountains; Franklin Furnace, New Jersey.

---

**SCAPOLITE** (*Wernerite*), $nNa_4Al_3Si_9O_{24}Cl + mCa_4Al_6Si_6O_{25}$.

Tetragonal, tetragonal bipyramidal class. Commonly as thick coarse, prismatic crystals, often large with dull and uneven faces.

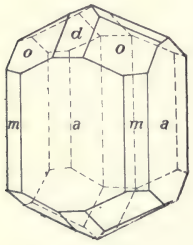



Fig. 660.

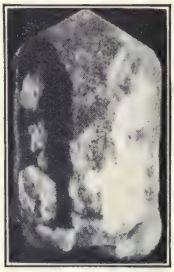


Fig. 661.—Scapolite. Ottawa County, Quebec.

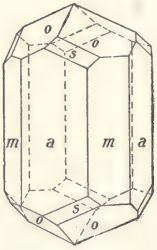



Fig. 662.

Crystals sometimes appear as though partially fused. The common forms are the prisms (*m* and *a*) and bipyramids (*o* and *d*) of the first and second orders; more rarely the bipyramid of the third order (*s*) is observed (Figs. 660 and 661). Occurs also in fibrous, coarse to fine granular, columnar, and compact masses.

Prismatic cleavage. Conchoidal fracture. Hardness 5 to 6. Spe-

cific gravity 2.6 to 2.8. Colorless, white, gray, greenish, bluish, or reddish. Vitreous to greasy luster. Translucent.

The composition varies greatly between *marialite*, $Na_4Al_3Si_9O_{24}Cl$, and *meionite*, $Ca_4Al_6Si_6O_{25}$. Some scapolites are readily decomposed by hydrochloric acid. All are quite easily fusible with intumescence. The scapolites alter to kaolin, jade, epidote, muscovite, biotite, albite, and various zeolites.

Commonly the result of metamorphism, and frequently found in granular limestones near the contact with igneous rocks; also in crystalline schists and volcanic ejectamenta. Typical associates are pyroxenes, amphiboles, apatite, garnet, titanite, zircon, and biotite. Some localities are: Arendal, Norway; Pargas, Finland; Laacher See, Rhenish Prussia; Mount Vesuvius; Ripon and Grenville, Quebec, and various places in Ontario, Canada; Bolton, Massachusetts; various places in northern New York; Franklin Furnace, New Jersey.

Scapolite is not important commercially.

**TITANITE** (*Sphene*), **$CaTiSiO_5$.**

Monoclinic, prismatic class. The crystal habit varies greatly. Disseminated crystals are generally wedge or envelope shaped, while attached crystals are apt to be tabular or prismatic (Figs. 663, 664, and

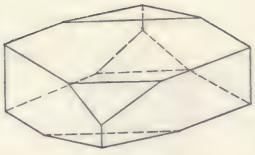


FIG. 663.

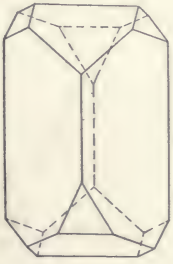


FIG. 664.

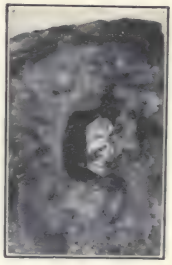


FIG. 665.—Titanite. Arendal, Norway.

665). Occurs also in compact or lamellar masses, and in disseminated grains.

Prismatic and domatic cleavages. Conchoidal fracture. Hardness 5 to 5.5. Specific gravity 3.4 to 3.6. Yellow, green, brown, reddish brown, red, or black in color. Vitreous luster, inclining to adamantine. Transparent to opaque.

$CaTiSiO_5$. Commonly considered as the calcium salt of the dimetasilicic acid, $H_2Si_2O_5$, in which one atom of silicon has been replaced by titanium. May also contain some iron or manganese. Fuses with intumescence on the edges to a dark colored glass. Only partially decomposed by hydrochloric acid, completely by sulphuric and hydrofluoric acids. Alters to rutile, brookite, or ilmenite.

Titanite occurs disseminated as an important accessory constituent of many igneous rocks, especially in hornblende granite, syenite, nepheline syenite, trachyte, phonolite, and diorite; also in crystalline schists and granular limestones. It is found attached in the cracks and cavities in granite, gneiss, and various schists. The common associates are the amphiboles, pyroxenes, apatite, zircon, scapolite, chlorite, feldspars, quartz, and various iron minerals. Some localities are: Laacher See, Rhenish Prussia; many places in Switzerland and Tyrol, especially St. Gothard, Tavetsch, and Zillerthal; Arendal, Norway; Ala, Piedmont; Ural Mountains; Grenville, Quebec, and Eganville, Renfrew County, Ontario, Canada; Sandford, Maine; Bolton and Lee, Massachusetts; various places in Lewis, Orange, and other counties, New York; Franklin Furnace, New Jersey; Magnet Cove, Arkansas.

The clear, green, yellow, or brownish varieties are used for gem purposes. They are very brilliant, possess an excellent adamantine luster, but are comparatively soft.

## Zeolites

This group contains several important secondary minerals, which are hydrated silicates of aluminum, calcium, sodium, and potassium. They are commonly found in good crystals, have comparatively low specific gravities, 2 to 2.4, and are rather soft, 3.5 to 5. Although generally colorless and transparent or translucent, they may be light colored, due to the presence of pigments. All zeolites are readily decomposed by hydrochloric acid, and many gelatinize on evaporation. They result from the decomposition of such minerals as nephelite, leucite, sodalite, and the feldspars. They are never found disseminated but always in cracks, crevices, or cavities in basic igneous rocks, such as basalt, diabase, and phonolites; more rarely in granite and mica schist. Their common associates are calcite, datolite, and pectolite.

**Natrolite** (*Needle Zeolite*), $Na_2Al(AlO)(SiO_3)_3.2H_2O$.

Orthorhombic, bipyramidal class. Crystals are slender prismatic and nearly square in cross-section; also acicular and arranged in radial or interlacing groups (Fig. 666). Occurs also in fibrous, granular, or compact masses.

Perfect prismatic cleavage. Hardness 5 to 5.5. Specific gravity 2.2 to 2.3. Colorless or white; also reddish, yellowish, or greenish. Transparent to translucent. Vitreous to silky luster.

$Na_2Al(AlO)(SiO_3)_3.2H_2O$. May contain some calcium and potassium. Fuses easily to colorless glass. Gelatinizes with acids. Yields water in a closed tube.

Occurs in cracks and cavities in basic igneous rocks. Common associates are chabazite, analcite, apophyllite, stilbite, calcite, and datolite.

Some notable localities are: Teplitz and Aussig, Bohemia; Fassathal,

Tyrol; Hohentwiel and Kaiserstuhl, Baden; Nova Scotia; Bergen Hill, New Jersey; Lake Superior copper district.

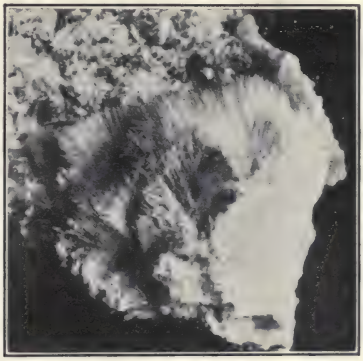


FIG. 666.—Natrolite. Paterson, New Jersey.

**ANALCITE, $Na_2Al_2(SiO_3)_4.2H_2O$.**

Cubic, hexoctahedral class. Generally in well developed tetragonal trisoctahedrons (Fig. 667); sometimes in combination with the cube (Fig. 668). Crystals are usually quite small, although some measuring a foot in diameter have been observed. Occurs also in compact, granular, or earthy masses.

Uneven to conchoidal cleavage. Hardness 5 to 5.5. Specific gravity 2.2 to 2.4. Colorless or white; also yellowish, reddish, or greenish. Vitreous luster. Transparent to nearly opaque.

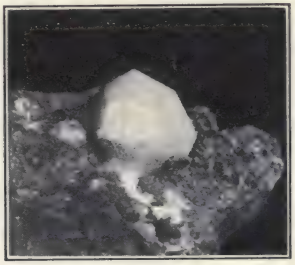


FIG. 667.—Analcite (tetragonal trisoctahedron). Lake Superior Copper District.

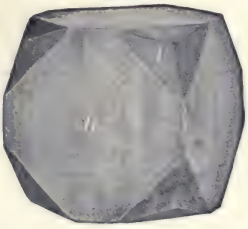


FIG. 668.

$Na_2Al_2(SiO_3)_4.2H_2O$. Chemically it is closely related to soda leucite. Fuses to a colorless glass. Gelatinizes with acids.

Analcite is commonly a secondary mineral occurring with the other zeolites, calcite, datolite, native copper, magnetite, and prehnite in basalt, diabase, granite, and gneiss. Some localities are: the Cyclopean Islands, near Sicily; Tyrol; Bohemia; Iceland; various places in Nova

Scotia; Bergen Hill, New Jersey; Lake Superior copper district; Table Mountain, Colorado.

**APOPHYLLITE, $H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$,**

Tetragonal, ditetragonal bipyramidal class. Crystals may be (1) long and square prismatic (Fig. 669), (2) pseudocubical (Fig. 671), (3) pyramidal (Fig. 672), or (4) thin tabular (Fig. 670). The most general combination consists of the prism of the second order (*a*), unit bipyramid of the first order (*o*), and the basal pinacoid (*c*). The prism faces are often brilliant and striated vertically, those of the basal pinacoid dull or rough, while the bipyramidal faces may be uneven. Occurs also massive, and in granular and lamellar aggregates.

Perfect basal cleavage. Uneven fracture. Hardness 4.5 to 5. Specific gravity 2.3 to 2.4. Generally colorless or white, also green, yellow, or reddish. Vitreous to pearly luster, with *fish-eye* opalescence on basal pinacoid. Usually transparent, rarely nearly opaque.

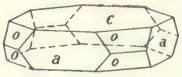



FIG. 670.

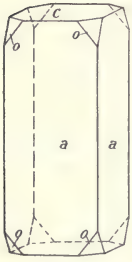



FIG. 669.

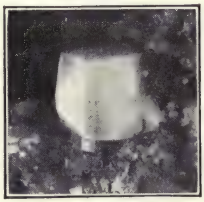


FIG. 671.—Apophyllite. Paterson, New Jersey.

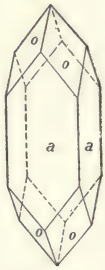



FIG. 672.

$H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$. The composition is somewhat uncertain. Small amounts of fluorine may be present. Exfoliates and fuses easily to a white enamel, coloring the flame violet. Decomposed by hydrochloric acid with a separation of silica. Alters to calcite, pectolite, and kaolin.

Occurs as a secondary mineral in cracks and cavities in basic igneous rocks, also in granite and gneiss. Common associates are natrolite, analcite, datolite, prehnite, pectolite, native copper, and calcite. Found in the Hartz Mountains; Freiberg, Saxony; Tyrol; Sweden; Iceland; Greenland; Nova Scotia; Bergen Hill, New Jersey; Table Mountain, Colorado; Lake Superior copper district; New Almaden, California.

**STILBITE** (*Desmine*), **$(Ca,Na_2)Al_2Si_6O_{16}.6H_2O$.**

Monoclinic prismatic class. Simple crystals are unknown, usually as tabular penetration twins. Very commonly several twin crystals

are arranged nearly parallel forming sheaf-like aggregates (Fig. 673). Occurs also in radial or globular aggregates.

Clinopinacoid cleavage. Uneven fracture. Hardness 3 to 4. Specific gravity 2.1 to 2.2. Vitreous to pearly luster. Transparent to translucent. Colorless or white, also brown, yellow, reddish.

FIG. 673.—Stilbite. Viesch, Switzerland.

$(Ca,Na_2)Al_2Si_6O_{16}.6H_2O$. May contain some potassium. Exfoliates, swells up, and fuses to a white glass. Decomposed by hydrochloric acid with a separation of silica.

Stilbite occurs with other zeolites, datolite, and calcite, in cavities in amygdaloidal basalts and related rocks; also in granites and crystalline schists and in ore deposits. Some localities are: Tyrol; Sweden; Iceland; Switzerland; Kilpatrick, Scotland; Nova Scotia; Bergen Hill, New Jersey; Lake Superior copper district; Table Mountain, Colorado.

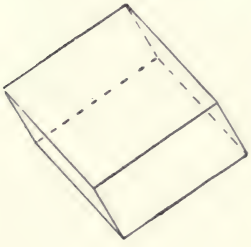


FIG. 674.

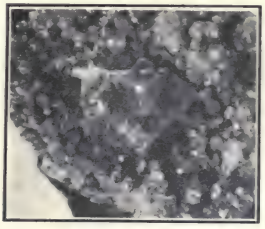


FIG. 675.—Chabazite (twinned). Paterson, New Jersey.

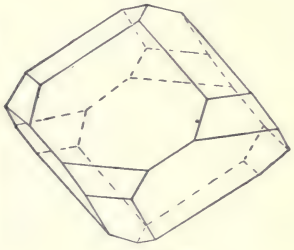


FIG. 676.

**CHABAZITE, $CaAl_2Si_6O_{16}.8H_2O$.**

Hexagonal, ditrigonal scalenohedral class. Generally in cube-like rhombohedrons (Fig. 674). Sometimes crystals are complex (Fig. 676) or twinned (Fig. 675). Occurs also in compact masses.

Rhombohedral cleavage. Uneven fracture. Hardness 4 to 5. Specific gravity 2.1 to 2.2. Colorless, white, reddish, yellowish, or brown. Vitreous luster. Transparent to translucent.

$CaAl_2Si_6O_{16}.8H_2O$. Composition varies considerably. May contain potassium and sodium replacing some of the calcium. Fuses with

intumescence to a nearly opaque, blebby glass. Decomposed by hydrochloric acid with a separation of silica.

Associated with the other zeolites, it generally occurs in cavities in basalts, phonolites, and related rocks. Some localities are: Giant's Causeway, Ireland; Aussig, Bohemia; Fårö Island, Sweden; Greenland; Iceland; Nova Scotia; Bergen Hill, New Jersey; Somerville, Massachusetts; Table Mountain, Colorado.

## CHAPTER XV

## GEMS AND PRECIOUS STONES

A considerable number of minerals occur with beautiful colors, some are transparent and exceedingly brilliant, while others possess a pleasing luster or sheen. Minerals of this character have, from the earliest times, been eagerly sought after for personal adornment and ornamentation. They constitute what we call *gems* and *precious stones*. In fact, it is well known that among primitive peoples many of these gem minerals were supposed to possess peculiar properties. Some were believed to bring good luck to the wearer, while others were thought to be useful in warding off or curing certain diseases.

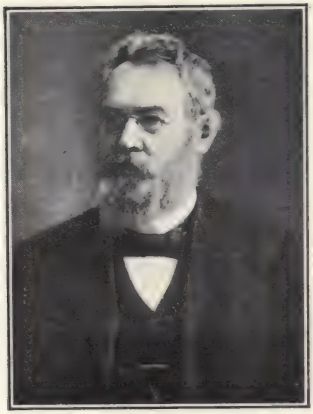


FIG. 677.—Max Bauer (1844–1918). Professor of mineralogy and petrography in the University of Marburg (1884–1918). Distinguished authority on gems and precious stones.

**Characteristics of Gems.**—The outstanding qualities of a gem are (1) *splendor* or *beauty*, (2) *durability*, (3) *rarity*, and (4) *fashion*. The beauty of a gem depends upon its transparency or clarity, brilliancy, color, luster, and fire. In some cases these qualities are seen to best advantage only when the stone is cut and polished. Red and blue diamonds, for example, embody all of these qualities to a marked extent. Sometimes the beauty of a gem does not depend upon all, but only upon several, of the above properties. Thus, the beauty of the ruby is the result of its excellent color, luster, and transparency. It is however almost totally lacking in fire. The opal is attractive principally on account of its fascinating play of colors. In the case of turquois, the beauty depends mainly upon a pleasing color. Water white diamonds are exceptionally beautiful, but they are devoid of color, their splendor being due to their brilliancy, luster, and fire.

Many minerals may be pleasing to the eye, but yet not be very serviceable as gems because of their inferior hardness. They do not wear well; that is, they lack durability. In order to serve to advantage as a gem, a mineral must be hard. It must resist abrasion. When worn on the hand, a stone is not only subject to the action of the ever present dust, which consists mainly of finely divided quartz particles and hence

is hard, but it is also subject to sudden shocks and knocks. Soft stones, even though they may take a beautiful polish and possess other necessary gem properties, become dull and worthless in a very short time. Stones of such inferior hardness serve fairly well in pins and brooches. A gem to be durable must therefore be hard, preferably harder than quartz. In fact, durability plays a prominent rôle in the classification of gems. Those which are generally classed as the distinctly *precious* stones—diamond, emerald, ruby, sapphire—all possess superior hardness, being decidedly harder than quartz. Soft gem minerals are generally regarded as *semi-precious.*

While durability is a fundamental quality of a gem, frequency of occurrence has much to do with determining the value of a mineral for gem purposes. Many minerals occur rather abundantly in nature, but only rarely are some of them found in such condition as to warrant their use as gems. Thus, the mineral beryl is fairly common. It occurs in large crystals, some of which weigh several tons, but the colors are then usually dull, and the crystals are not transparent. The green transparent variety, called the emerald, is however seldom found and is accordingly very highly prized. There are other transparent varieties of beryl, such as golden beryl and aquamarine, but these are more frequently found and are not as valuable as the rarer emerald. Other things being equal, the rarer the stone, the greater its value, for there are many people who will always desire that which is rare and exceptional and be willing to pay enormous prices in order to obtain those gems which others cannot afford.

Fashion and style exert an enormous influence upon the favor with which a gem is received. Indeed, it frequently happens that as the result of a change in fashion or style, an excellent gem mineral—excellent with respect to the various properties referred to above—is suddenly discarded for some new and perhaps inferior stone. During the last thirty years many stones have thus come into favor, most of which are of bright color. Hence, the number of minerals which are to be counted as gems is subject to change, the tendency being toward an extension of the list.

**List of Gems.**—The following tabulation contains the minerals, described in this text, which are used as gems. In each case the page is indicated where the mineral has been fully described. Where special terms have been assigned to varieties of gem quality, these are also given.

**Diamond, 188**
**Beryl, 313** (*Emerald, Aquamarine, Yellow* or *Golden Beryl, Morganite*)
**Corundum, 228** (*Ruby, Sapphire, White Sapphire, Golden Sapphire, Oriental Emerald, Oriental Topaz, Oriental Amethyst*)
**Topaz, 283** (*Precious Topaz*)
**Spinel, 267** (*Ruby Spinel, Rubicelle, Blue Spinel*)
**Garnet, 290** to **293**
Grossularite (*Hessonite, Cinnamon Stone*)

Pyrope (*Cape Ruby, Arizona Ruby*)
Spessartite
Almandite (*Carbuncle, Rhodolite*)
Uvarovite
Andradite (*Topazolite, Demantoid*)
**Tourmaline, 284** (*Rubellite*)
**Olivine, 289** (*Peridot*)
**Zircon, 225** (*Hyacinth, Jacinth, Jargon*)
**Chrysoberyl, 271** (*Alexandrite, Cat's Eye, Cymophane*)
**Opal, 232** (*Precious Opal, White Opal, Black Opal, Fire Opal*)
**Quartz, 220** (*Rock Crystal, Amethyst, Rose Quartz, Smoky Quartz, Cairngorm Stone, False Topaz, Spanish Topaz, Citrine, Aventurine, Rutilated Quartz, Cat's Eye, Tiger's Eye, Chalcedony, Carnelian, Sard, Chrysoprase, Heliotrope, Bloodstone, Agate, Onyx*)
**Turquois, 276**
**Jade, 311** (*Nephrite, Jadeite*)
**Feldspar, 315**
Orthoclase (*Moonstone*), 317
Microcline (*Amazon Stone, Amazonite*), 318
Albite (*Moonstone*), 320
Labradorite (*Labrador Spar*), 321
**Pyroxene, 304**
Hypersthene, 304
Diopside, 305
Spodumene (*Hiddenite, Kunzite*), 308
Rhodonite, 309
**Titanite, 323** (*Sphene*)
**Vesuvianite, 288** (*Californite*)
**Lazurite, 303** (*Lapis Lazuli*)
**Serpentine, 297** (*Precious Serpentine*)
**Epidote, 286**
**Malachite and Azurite, 252** (*Malachite Matrix, Azurmalachite*)
**Chrysocolla, 293**
**Cyanite, 282**
**Datolite, 283**
**Staurolite, 279**
**Andalusite, 281**
**Gypsum, 264** (*Satin Spar*)
**Pyrite, 208**
**Hematite, 230**

**Popular Names of Gems.**—Many of the names applied to gem minerals are of very ancient origin and, hence, were in use long before mineralogy was developed as a science. Considerable ambiguity has, therefore, arisen by the simultaneous use of popular terms by jewelers and of scientific names by mineralogists. Indeed, many of the popular terms are intentionally misleading. Thus, yellow quartz or citrine is commonly called in the trade *spanish, brazilian,* or *orientat lopaz.* Popular names have frequently been based upon color and, hence, it is not surprising to find the term ruby incorporated in several of the popular names given to gem stones of a red color: *ruby spinel, balas ruby,* and *rubicelle* for

red spinel; *cape ruby* and *Arizona ruby* for pyrope garnet; and *rubellite* for red tourmaline. Popular names of this character suggest relations with more valuable stones which are not warranted by the facts. Obviously, all ambiguity and misconceptions would be avoided if only the scientific names of the mineralogist were used.

Photo by the Champlain Studios, Inc., New York City.
FIG. 678.—George F. Kunz (1856 ——). New York City. Author of many publications on gems and precious stones.

**Methods of Identification.**—Rough and uncut gem stones can be readily determined by means of their physical properties in the same way as other minerals. This usually involves the use of a set of mineral tables, such as are found on pages 380 to 547. When the stones are cut and polished, the properties generally used for determination are

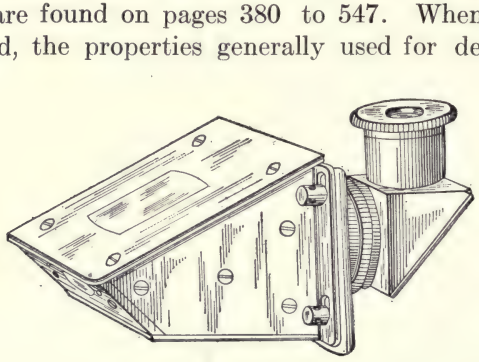


FIG. 679.

color, index of refraction,* dispersion, fracture or cleavage as revealed around the prongs of the setting, inclusions, and dichroism. If it is necessary to determine the hardness of a gem, great care should be exercised not to injure a soft but otherwise perfectly good stone. When stones are

* This determination can be easily and quickly made by using Smith's hand total refractometer (Fig. 679).

unmounted, a determination of the specific gravity can often be made the basis of an accurate recognition of the gem under consideration.

**Weight.**—Gems are usually sold by weight, which is expressed in carats. This standard of weight was until very recently a variable quantity, having originally been determined by the weight of certain grains or leguminous seeds. Thus, the carat used in various gem centers differed considerably when expressed in terms of the metric system of weights. This is clearly shown by the values of the carats formerly in use in the following cities:—Florence, 0.1972 grams; London, 0.2053; Madrid, 0.20539; Amsterdam, 0.2057; Frankfurt am Main, 0.20577; Vienna, 0.20613. In 1913 the metric carat, which equals 0.200 grams, was made the standard in the United States. This unit has also been adopted in practically all the large countries of the world.

FIG. 680.

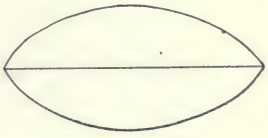


FIG. 681.

**Cutting of Gems.**—Although gem minerals are frequently found in nature in beautiful and well-developed crystals, they are rarely adapted for use as gems without suitable cutting and polishing. While crystals may show excellent reflections, the full optical splendor of such gem minerals is best brought out by cutting or grinding the specimen into symmetrical shapes, which will allow the stone to appear as brilliant as possible, show its best color, and exhibit the maximum amount of fire. This process of cutting involving the production of artificial faces or facets, as these plain surfaces are called, is of comparatively recent origin.

FIG. 682.

FIG. 683.

FIG. 684.

Louis de Berquem is credited with having discovered this process about 1456.

The ancients contented themselves with simply polishing the natural crystal faces, or they ground the stone into certain rounded shapes. The *cabochon* cuts are, hence, the oldest of the various styles of cutting still in common use. The following types may be differentiated:

(1) *Double* or *convex cabochon.*—This involves generally circular, elliptical, or oval forms with two convex surfaces, the upper side being more convex than the lower (Fig. 680). When the convexity is the same above and below, the cut is sometimes called *lentil shape* (Fig. 681).

(2) *High cabochon.*—This is somewhat similar to (1), but the upper

portion is very much higher and, hence, more convex than the under side (Fig 682).

(3) *Simple or plain cabochon.*—In this cut the upper side is convex as in (1) and (2), but the under side is a plain surface. Stones with this style of cutting are mounted with the plain surface down (Fig. 683).

(4) *Hollow* or *concavo-convexo cabochon*, also called *shell cut.* In this style the upper side is convex, but the under portion is hollowed out (Fig. 684).

FIG. 685.—Diamond cleaver at work.*

The cabochon cuts are used for stones exhibiting sheens, play of colors, opalescence, and asterism; thus, for tiger's eye, opal, moonstone, and star sapphires. They are also used for many colored stones, for example, garnet, amethyst, turquois, and chrysocolla. The hollow cabochon cut is generally employed for transparent but deeply colored stones through which very little light could pass if cut in the other styles; for example, the almandite variety of garnet.

* Figs. 685, 693 and 694 are views taken in the Diamond Cutting Works of Messrs. Stern Brothers and Company, New York.

The principal style of cutting involving facets is the *brilliant cut.* In this cut the octahedron, either natural or produced by cleavage, is made the basis, as is shown in Figs. 685 and 686. The upper and lower portions are removed in such a manner that when the stone is cut, the portion above the edge *G*, which is termed the *girdle*, is generally one-half as thick as the part below the girdle. The upper portion of the cut stone is

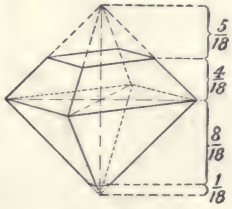



FIG. 686.

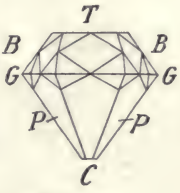



FIG. 687.

FIG. 688.

called the *crown* or *bizet*, while the lower part is the *pavilion* or *base.* The uppermost facet *T* is the *table*, and *C* is the *culet* (Figs. 687 and 688). Commonly there are fifty-six facets between the table and the culet. In some cases, however, diamonds are cut in this style with as many as sixty-six or seventy-four facets, inclusive of the table and the culet. Definite

FIG. 689.

FIG. 690.

relations between the height of the crown, depth of the pavilion, and width of the stone must be observed if the cut gem is to exhibit the maximum of brilliancy and fire. Depending upon the character of the rough material, the outline of the cut stone varies, being either circular, quadratic, oval, elliptical, or pear-shaped. The diamond is cut almost exclusively in this style.

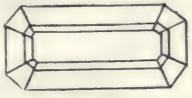


FIG. 691.

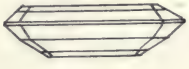


FIG. 692.

The *rose* cut has twenty-four triangular facets with a flat base (Figs. 689 and 690). This style of cutting is one of the earliest involving facets but is not employed much at present. Figures 691 and 692 illustrate step, trap, or cushion cuts, which are frequently used for colored stones.

In cutting gems, the stone is held in some cement and placed against

a rapidly revolving metallic wheel or disk containing or covered with some abrasive, such as diamond dust, carborundum, or emery. The position and inclination of the various facets are determined by the eye of the

FIG. 693.—Diamond cutters.

cutter, who obviously must exercise great judgment in order to cut stones to the best advantage. These cutters become very expert and rarely does an experienced cutter exceed the permissible limits of varia-

FIG. 694.—Diamond polisher.

tion in the angles between the different facets. After the facets have been produced, they are polished in much the same manner as they were cut, except that some polishing material like tripolite or rouge, instead

of an abrasive, is used. Diamonds are usually cut and polished by men who specialize on the diamond, while a lapidary is one who cuts and polishes all other types of gems. Antwerp, Amsterdam, Paris, London, Hanau, Idar, New York, and Boston are important gem cutting centers.

**Synthetic Gems.**—A synthetic gem is one prepared in the laboratory, and in its chemical and physical properties is identical with the corresponding natural gem. For many years scientists have endeavored to produce the diamond in the laboratory. Prominent among the many investigators who have worked on this problem, are Moissan, and Noble and Crookes, who succeeded in obtaining small diamonds of microscopic sizes. All attempts to obtain synthetic diamonds of such sizes as to be of commercial importance have thus far resulted in failure.

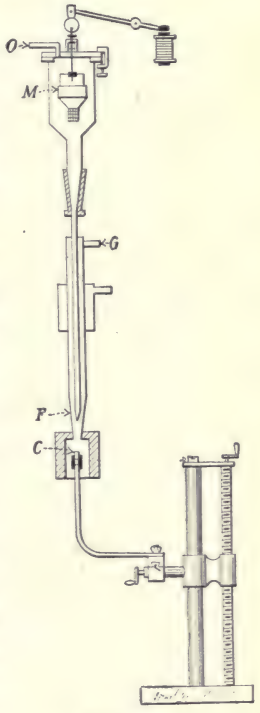


FIG. 695.

The most important synthetic gems are those having the composition and physical properties of the various varieties of corundum; that is, synthetic rubies and sapphires. At present these are manufactured on a large scale, and they differ from the natural stones only in minor details. In fact, in many instances the cut synthetics exhibit greater splendor and are usually much cleaner than natural stones.

The apparatus for producing these synthetic rubies and sapphires was devised by Verneuli (Fig. 695). It consists of a vertical blowpipe, burning a mixture of illuminating gas and oxygen, which enter at G and O, respectively. By means of suitable mechanism, very finely divided particles of aluminum oxide, $Al_2O_3$, are introduced at M. These particles mix with the gases and fuse in the very hot flame at F, which is directed against a small fire clay support C. These fused particles collect on this clay support at first as a small drop, which slowly increases in size, as the process continues, until a fairly large and inverted conical or pear-shaped, colorless drop, called the *boule* is formed (Fig. 696). These boules are broad on top and very narrow below where supported on the fire-clay cone. They usually weigh from 25 to 30 carats. Although the internal structure of such boules is the same as that of the natural colorless corundum or white sapphire, the only indication of crystal faces usually to be observed is a slight flattening of one of the upright sides. This flattened surface corresponds in position to the basal pinacoid in the natural gem.

By the addition to the $Al_2O_3$ of a small amount of chromium oxide, boules of a red color are obtained. These correspond to the ruby. The addition of the oxide of titanium gives the deep blue color of the sapphire proper. The yellow color of the beautiful golden sapphire is produced when some nickel compound and other substances, at present kept secret, are added. In chemical composition and all physical properties, such as hardness, specific gravity, indices of refraction, and so forth, these synthetic gems are identical with those occurring in nature. Due to the presence of inclusions, tension cracks, and peculiar structure lines, cut synthetic gems can in most instances be easily distinguished from natural stones. In some cases, however, especially if the cut stones are about one-half carat or less in size, their synthetic character may be very difficult to determine.

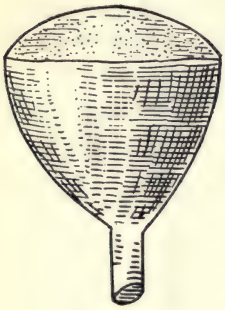


FIG. 696.

Cut synthetic rubies and sapphires can be obtained at prices ranging from $1.00 to 10.00 per carat, depending upon the quality of the stone. These prices are about one-twentieth of those charged for natural gems of the same grade. Not all of these synthetics are sold as gems. A large percentage is used as *jewels* in the manufacture of watches and in delicate physical and electrical instruments, where hard bearing surfaces are required.

## CHAPTER XVI

## CLASSIFICATION OF MINERALS ACCORDING TO ELEMENTS

It is often desirable to refer to the more important minerals in which elements of economic importance occur, and the following tabulations have been prepared to meet this need. Following each table there is a discussion of the uses of the important commercial minerals under consideration and whenever possible statistics of production are given. The minerals are given under each element in the order in which they have been described in the text. Page references to the detailed descriptions are given after the names of the minerals.

### ALUMINUM

| | | |
|---|---|---|
| **CORUNDUM, 228** | Hexagonal | $Al_2O_3$ |
| **BAUXITE, 235** | Unknown | $Al_2O(OH)_4$ |
| **CRYOLITE, 240** | Monoclinic | $Na_3AlF_6$ |
| **ALUNITE, 262** | Hexagonal | $K_2(Al.2OH)_6(SO_4)_4$ |
| **SPINELS, 267** | Cubic | $Mg(AlO_2)_2$, etc. |
| **Chrysoberyl, 271** | Orthorhombic | $Be(AlO_2)_2$ |
| **Wavellite, 276** | Orthorhombic | $(Al.OH)_3(PO_4)_2.5H_2O$ |
| **Turquois, 276** | Triclinic | $H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$ |
| **STAUROLITE, 279** | Orthorhombic | $HFeAl_5Si_2O_{13}$ |
| **ANDALUSITE, 281** | Orthorhombic | $Al_2SiO_5$ |
| **Sillimanite, 282** | Orthorhombic | $Al_2SiO_5$ |
| **CYANITE, 282** | Triclinic | $Al_2SiO_5$ |
| **TOPAZ, 283** | Orthorhombic | $Al_2(F,OH)_2SiO_4$ |
| **TOURMALINE, 284** | Hexagonal | $H_{20}B_2Si_4O_{21}$ |
| **EPIDOTE, 286** | Monoclinic | $Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$ |
| **VESUVIANITE, 288** | Tetragonal | $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$ |
| **GARNETS, 290** | Cubic | $R''_3Al_2(SiO_4)_3$ |
| **MICAS, 294** | Monoclinic | $H_2KAl(SiO_4)_3$, etc. |
| **CHLORITES, 297** | Monoclinic | $H_4Mg_2Al_2SiO_9$ |
| **KAOLINITE, 301** | Monoclinic | $H_4Al_2Si_2O_9$ |
| **NEPHELITE, 301** | Hexagonal | $(Na,K)_8Al_8Si_9O_{34}$ |
| **Sodalite, 303** | Cubic | $Na_4Al_2(Al.Cl)(SiO_4)_3$ |
| **SPODUMENE, 308** | Monoclinic | $LiAl(SiO_3)_2$ |
| **AMPHIBOLES, 309** | Orthorhombic and Monoclinic | Silicates of Al,Ca,Mg,Fe |
| **LEUCITE, 313** | Orthorhombic and Cubic | $K_2Al_2Si_4O_{12}$ |
| **BERYL, 313** | Hexagonal | $Be_3Al_2Si_6O_{18}$ |
| **FELDSPARS, 315** | Monoclinic and Triclinic | $KAlSi_3O_8$, etc. |
| **ZEOLITES, 324** | Various systems | Hydrated silicates |
| **SCAPOLITE, 322** | Tetragonal | $Ca_4Al_6Si_6O_{25}$, etc. |

Aluminum is the most abundant metal in nature and the minerals in which this element is an important constituent are exceedingly numerous. Only bauxite, cryolite, and alunite serve as sources of aluminum or its compounds. Bauxite is used as a source of metallic aluminum and aluminum salts, and also in the manufacture of bauxite bricks and abrasives, such as *alundum*, *aloxite*, *exolon*, and *lionite*. These products are made by fusing bauxite in an electric furnace. The total production of artificial abrasives made from bauxite in 1917 was 48,460 short tons. Cryolite is used as the flux in the electrolytic method for the extraction of the metal from bauxite, while alunite furnishes a small amount of potassium salts, together with alumina as a by-product.

In the extraction of aluminum, the crude ore (bauxite) is fused with sodium carbonate, and the fusion leached with water. Upon passing carbon dioxide through the filtrate, the hydroxide of aluminum is precipitated which is then ignited to the oxide. Another method, sometimes employed to remove most of the impurities from the ore, consists of fusing the bauxite in an electric furnace with sufficient carbon to reduce silica, titanic oxide, and ferric oxide. The alumina is not affected. In the electrolysis, cryolite is placed in tanks lined with carbon which acts as the cathode, while suspended carbon cylinders serve as the anode. The cryolite melts and readily dissolves the alumina which is added. The current decomposes the latter with the separation of metallic aluminum which collects in the bottom of the tank. The value of primary metallic aluminum produced in the United States in 1918 was $41,159,000.

Metallic aluminum finds extensive use on account of its low density, toughness, durability, and resistance to corrosion. Many alloys of aluminum have been prepared. The most important are those with copper, zinc, tin, nickel, magnesium, manganese, silver, and cadmium. *Thermit*, used in welding, is a mixture of aluminum and iron oxide, while the explosive *ammonal* consists of aluminum dust and ammonium nitrate. Alum and aluminum sulphate are the chief chemical salts and are employed in water purification, dyeing, and tanning. Bauxite bricks containing about 77 per cent. alumina are used in the construction of copper, iron, and lead furnaces, and of cement kilns.

Bauxite of commercial grade should carry at least 52 per cent. $Al_2O_3$, less than 3 per cent. $TiO_2$, and not more than 15 per cent. of the combined oxides of silicon and iron. The production of bauxite in United States in 1918 totaled 605,721 long tons, of which 562,892 tons were obtained from Arkansas (about 90 per cent.) and 42,829 tons from Georgia, Tennessee, and Alabama. In 1918, 20,286 short tons of alum and 209,079 short tons of aluminum sulphate were produced. The quantity of cryolite imported from Greenland in 1918 was 1,950 long tons, valued at $97,500 or $50 per ton.

### ANTIMONY

| | | |
|---|---|---|
| **STIBNITE, 204** | Orthorhombic | $Sb_2S_3$ |
| **Pyrargyrite, 217** | Hexagonal | $Ag_3SbS_3$ |
| **Bournonite, 217** | Orthorhombic | $Pb_2Cu_2Sb_2S_6$ |
| **TETRAHEDRITE, 218** | Cubic | $M''_4Sb_2S_7$ |

Of the above named antimony minerals stibnite is the most important. Some antimony is also recovered from antimonial lead ores carrying from 12 to 18 per cent. of antimony. Antimony metal is used chiefly in the manufacture of alloys. These alloys include *type metal* (lead, antimony, and tin), *babbitt, antifriction,* or *bearing metal,* (antimony, tin, with small amounts of lead, copper, bismuth, zinc, or nickel), *britannia* or *white metal* (tin, antimony, copper, with some zinc), and so forth. Antimony imparts hardness to lead and prevents it from contracting when solidifying from a molten condition. The tetraoxide ($Sb_2O_4$) is used in making opaque white enamel and other sanitary ware. Salts of antimony are used in medicine and as a mordant in dyeing, while the sulphide of antimony is employed for vulcanizing and coloring rubber and also as paint pigments.

Under normal conditions United States is not a large producer of antimony ores, importing practically its entire supply from China, Bolivia Mexico, and Japan. In 1918 the production of antimony ores in the United States was confined to the Western States and Alaska. The total reported was 190 short tons containing 50 tons of the metal.

### ARSENIC

| | | |
|---|---|---|
| **Native Arsenic, 194** | Hexagonal | As |
| **REALGAR, 203** | Monoclinic | AsS |
| **ORPIMENT, 204** | Monoclinic | $As_2S_3$ |
| **Niccolite, 208** | Hexagonal | NiAs |
| **Cobaltite, 209** | Cubic | CoAsS |
| **Smaltite, 209** | Cubic | $CoAs_2$ |
| **ARSENOPYRITE, 211** | Orthorhombic | FeAsS |
| **PROUSTITE, 217** | Hexagonal | $Ag_3AsS_3$ |
| **TETRAHEDRITE, 218** | Cubic | $M''_4As_2S_7$ |
| **Enargite, 219** | Orthorhombic | $Cu_3AsS_4$ |

Arsenopyrite is the most important arsenical mineral. The commercial uses of arsenic are very limited. Shot metal is an alloy of arsenic and lead. Arsenious oxide is used in the manufacture of glass for counteracting the iron coloration, and of Paris green, and other insecticides. The minerals realgar and orpiment are employed in paints and in the dyeing of cloth.

The production of arsenic is recorded in terms of *white arsenic,* arsenious oxide, $As_2O_3$, very little of which is obtained directly from arsenic minerals. Large quantities are however available as a by-product in the smelting of copper, cobalt, gold, silver, and lead ores. The production in 1918 was 6,323 short tons of $As_2O_3$, valued at $1,213,000.

### BARIUM

| | | |
|---|---|---|
| **WITHERITE, 251** | Orthorhombic | $BaCO_3$ |
| **BARITE, 256** | Orthorhombic | $BaSO_4$ |

Barite (barytes) is the more important of the above minerals, commercially. It is used chiefly as a pigment in mixed paints. *Lithopone,* one of the chief constituents of sanitary flat wall paints, is a mixture of 70 per cent. barium sulphate, 25 to 29 per cent. zinc sulphide, and 1 to 5 per cent. zinc oxide. *Blanc fixé* or permanent white is artificially prepared barium sulphate. Ground barite is used in the manufacture of rubber goods, artificial ivory, and heavy glazed paper, such as playing cards, and bristol board. The barium salts have a wide variety of uses: barium binoxide ($BaO_2$) in the preparation of hydrogen peroxide, barium chloride as a water softener, the carbonate and chloride to prevent efflorescence on bricks and as insecticides, and the carbonate, sulphate, or nitrate in the manufacture of optical glass.

Barite is obtained mainly from Georgia, Missouri, Tennessee, and Kentucky, and in 1918 the production totaled 155,241 short tons valued at $1,044,337.

### BERYLLIUM

| | | |
|---|---|---|
| **Chrysoberyl, 271** | Orthorhombic | $Be(AlO_2)_2$ |
| **BERYL, 313** | Hexagonal | $Be_3Al_2(SiO_3)_6$ |

Aside from the use of beryllium minerals as gems, the application of beryllium compounds in the arts is restricted to a small amount consumed in the manufacture of incandescent gas mantels.

### BISMUTH

| | | |
|---|---|---|
| **Native Bismuth, 195** | Hexagonal | Bi |

Bismuth is extensively used in alloys with lead, tin, copper, antimony, and cadmium. The melting point of some of these alloys is as low as 64°C and they are therefore employed as safety fuses for electrical apparatus, safety plugs for boilers, and for automatic sprinklers. As these alloys expand upon solidifying from a molten condition they are employed in type metal. Bismuth salts are used in dressing wounds. The nitrate is sometimes given internally before producing a roentgenograph, as bismuth salts are opaque to X-rays. The salts are also used in calico printing and in the manufacture of high refractive glass.

Very little native bismuth is mined in the United States. Almost the entire domestic production is obtained as a by-product in the electrolytic refining of lead, the bismuth being recovered from the anode slime. This source yields about 200,000 lbs. of the metal annually.

### BORON

| | | |
|---|---|---|
| Colemanite, 271 | Monoclinic | $Ca_2B_6O_{11}.5H_2O$ |
| Datolite, 283 | Monoclinic | $Ca(B.OH)SiO_4$ |
| TOURMALINE, 284 | Hexagonal | $H_{20}B_2Si_4O_{21}$ |

Commercially, the most important boron compound is borax, which is obtained by treating colemanite with sodium carbonate or sulphate. Borax is used in assaying, soldering, welding of metals, and in the manufacture of flint glass. Because of its antiseptic and cleansing properties it is also used in the preservation of food and in the manufacture of soap, washing powders, and ointments. Chromium borate is a green pigment employed in calico printing, and the borate of manganese is sometimes used as a drier in paints and oils.

The entire output of crude borate (colemanite) in United States in 1917 was obtained from a few mines in southern and southeastern California, and amounted to 109,944 short tons, valued at $2,561,958.

The production of gem varieties of tourmaline in 1918 was restricted to California and Maine and amounted to $6,206.

### CALCIUM

| | | |
|---|---|---|
| FLUORITE, 239 | Cubic | $CaF_2$ |
| CALCITE, 242 | Hexagonal | $CaCO_3$ |
| DOLOMITE, 245 | Hexagonal | $CaMg(CO_3)_2$ |
| ARAGONITE, 249 | Orthorhombic | $CaCO_3$ |
| ANHYDRITE, 254 | Orthorhombic | $CaSO_4$ |
| Scheelite, 259 | Tetragonal | $CaWO_4$ |
| GYPSUM, 264 | Monoclinic | $CaSO_4.2H_2O$ |
| Colemanite, 271 | Monoclinic | $Ca_2B_6O_{11}.5H_2O$ |
| APATITE, 273 | Hexagonal | $Ca_5F(PO_4)_3$ |
| Datolite, 283 | Monoclinic | $Ca(B.OH)SiO_4$ |
| EPIDOTE, 286 | Monoclinic | $Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$ |
| Orthite, 287 | Monoclinic | $Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$ |
| VESUVIANITE, 288 | Tetragonal | $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$ |
| GARNET, 290 | Cubic | $Ca_3Al_2(SiO_4)_3$, etc. |
| PYROXENES, 304 | Orthorhombic, Monoclinic, and Triclinic | $CaMg(SiO_3)_2$, etc. |
| AMPHIBOLES, 309 | Orthorhombic, Monoclinic, and Triclinic | $CaMg_3(SiO_3)_4$, etc. |
| Anorthite and PLAGIOCLASES, 319 | Triclinic | $CaAl_2Si_2O_8$, etc. |
| SCAPOLITE, 322 | Tetragonal | $Ca_4Al_6Si_6O_{25}$, etc. |
| TITANITE, 323 | Monoclinic | $CaTiSiO_5$ |
| ZEOLITES, 324 | Various systems | Hydrated silicates |

Calcium is one of the most abundant metals in nature and is an important constituent of many minerals. Of those listed above, fluorite, calcite, dolomite, scheelite, gypsum, colemanite, and apatite are of prime importance commercially. However, the production and uses of calcite, dolomite, and gypsum only will be given here.

*Calcite and Dolomite.*—The value of limestone, massive forms of calcite and dolomite, sold in United States in 1917 was $46,263,379, or 56.3 per cent. of the total value of all stone sold in that year, while the value of marble was placed at $6,330,387. The distribution of this production is shown summarized below:

| | Building | Monumental | Paving | Curbing | Flagging | Rubble | Riprap | Crushed | Other uses |
|---|---|---|---|---|---|---|---|---|---|
| Limestone | $4,115,366 | ..... | $7,273 | 51,927 | $8,327 | $270,327 | $854,884 | $17,541,098 | $23,414,132 |
| Marble | $3,702,563 | $2,397,717 | ..... | ..... | ..... | ..... | ..... | ..... | $230,107 |

Under other uses, in the case of limestone, are included furnace flux valued at $18,679,213, stone for alkali works and sugar factories, valued at $2,084,036, and ground stone for agricultural purposes, valued at $1,352,397. Furnace flux, terrazzo, and marble dust are included under other uses of marble. In addition, large quantities of limestone are employed in the manufacture of cement and lime. It is estimated that in 1917 these industries used the following quantities of limestone.

| | |
|---|---|
| Portand cement . . . . . | 24,640,230 short tons |
| Natural cement . . . . . | 102,260 short tons |
| Lime . . . . . | 7,194,000 short tons |

The leading limestone producing States, according to rank, in 1917 were Pennsylvania, Ohio, Indiana, New York, Michigan, and Illinois, each with a production of more than $3,000,000.

*Gypsum.*—This mineral is used in both the uncalcined and calcined condition. In the former state its chief uses are (1) as a retarder in Portland cement, (2) as a pigment base for paints, especially in making cold water paints, (3) as a filler for paper and cloth, and (4) as land plaster or fertilizer. The action of gypsum as a fertilizer is indirect, decomposing complex silicates of magnesia and potash, thus liberating these compounds for plant food. Ground gypsum neutralizes acid soils and, because of its ability to absorb moisture from the atmosphere, promotes the growth of grain especially in the early stages by keeping the moisture near the surface.

Calcined gypsum is used chiefly in wall plasters, plaster boards, gypsum blocks and tile, molds for pottery and terra cotta, surgical casts, and for many other purposes. Gypsum tile 3 in. thick and 30 in. long, reinforced with metal is frequently used for roof decks of laundries, foundries, and textile mills where condensation of moisture causes considerable trouble. As gypsum has a low heat conductivity its use largely prevents this condensation or drip. *Keene's cement,* which differs from ordinary wall plasters in the time of setting and its greater hardness, is made by

burning pure gypsum at a low temperature, then immersing in a solution of alum, aluminum sulphate, or borax and recalcining at about 500°C.

Gypsum is produced in eighteen states and Alaska. New York is the largest producer, Iowa second, and Michigan third. Almost inexhaustible deposits are to be found west of the Mississippi River. In the single state of Wyoming beds from six to twenty feet in thickness are exposed for a thousand miles. The production in United States in 1918 was 2,057,015 short tons, distributed according to uses as follows:

*Uncalcined*

| | |
|---|---|
| Portland cement | 403,587 short tons |
| Land plaster | 64,571 short tons |
| Other purposes | 1,986 short tons |

*Calcined*

| | |
|---|---|
| Plaster Paris, wall plasters, etc. | 1,174,359 short tons |
| Glass factories | 13,567 short tons |
| As boards, tile, blocks, etc. | 140,343 short tons |

## CARBON

| | | |
|---|---|---|
| **DIAMOND, 188** | Cubic | C |
| **GRAPHITE, 192** | Hexagonal | C |

Carbon is also an essential constituent of the carbonates, pages 241 and 253 and organic substances as petroleum, asphalt, and coal.

*Diamond.*—Several hundred carats of diamonds were reported from Pike County, Arkansas in 1918, including a yellow colored octahedron weighing 17.85 carats, a flat, clear stone of 11 carats, and a number of smaller stones weighing several carats each. It is estimated that at least 4,000 stones were found in the Arkansas diamond district up to July 1, 1916. The values of other scattered finds rarely exceed a few thousand dollars annually.

*Graphite.*—The trade makes a sharp distinction between crystalline and amorphous graphite. By the former is meant flake graphite of sufficient size to be visible to the naked eye. By far the most important use of graphite is in the manufacture of crucibles used in the steel, brass, and bronze industries. For this purpose a flaky or fibrous graphite is essential and the Ceylon lump is generally preferred, although it is sometimes mixed with 10 to 25 per cent. of American flake graphite. For crucibles graphitic carbon should exceed 85 per cent. and at the same time be practically free from mica, pyrite, and iron oxide. Graphite crucibles are superior to clay crucibles because of their infusibility, conductivity of heat, and ability to withstand sudden temperature changes. As graphite has but little binding strength, clay, sand, and kaolin are added in the proportion of about 3 parts of graphite, 2 parts of clay, 1 part of sand, and smaller amounts of kaolin.

Except for the manufacture of crucibles, amorphous graphite is suitable for all other purposes. For paint and foundry facings a high degree of purity is not demanded, but for lubricants, pencils, and electric purposes high grade material is essential. In the manufacture of self-lubricating metals, molten metal is forced into graphite and the resulting mixture contains about 60 per cent. by weight or 25 per cent. by volume of the metal.

Imported crystalline graphite is obtained chiefly from Ceylon and Madagascar, while Alabama, New York, and Pennsylvania are the principal domestic sources. The better grades of amorphous graphite are imported from Mexico and Chosen (Korea). The production and importation in 1918 is shown below.

*Domestic Production*

| | |
|---|---|
| Crystalline | 6,431 short tons |
| Amorphous | 6,560 short tons |
| Total | 12,991 short tons |

Graphite imported in 1918 totaled 19,498 short tons.

## CERIUM

| | | |
|---|---|---|
| **Monazite, 272** | Monoclinic | $(Ce,La,Di)PO_4$ |
| **Orthite, 287** | Monoclinic | $Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$ |

When struck or scratched alloys of cerium readily emit sparks and this property is utilized in many forms of automatic lighters. Because of the great affinity of cerium for oxygen it is also used as a reducing agent in the production of metallic zirconium and thorium. Cerium sulphate is employed in the manufacture of aniline black, in photography for the purpose of removing silver from over-developed negatives, and as a catalyst in the contact process for the manufacture of sulphuric acid. Recently cerium compounds have been proposed for use in color photography and arc lamp electrodes. The oxide, ceria, is employed very extensively as a constituent of incandescent mantles.

## CHROMIUM

| | | |
|---|---|---|
| **Crocoite, 258** | Monoclinic | $PbCrO_4$ |
| **CHROMITE, 270** | Cubic | $(Fe,Cr)[(Cr,Fe)O_2]_2$ |

Chromite is by far the more important. When added in small amounts (1 to 2 per cent.) to steel, chromium increases its hardness. Chrome steel is used in the manufacture of armor plate, armor piercing projectiles, and for high speed tools. Chromite is often employed to line copper and steel furnaces. For this purpose it has certain advantages over magnesite, as it resists corrosion, withstands sudden changes of tempera-

ture, and requires less delicate handling. Compounds of chromium are used as pigments, mordants in dyeing and printing cloth, and in tanning leather.

The chief foreign sources of chromite in recent years have been Rhodesia, New Caledonia, and Canada. In 1918, 100,224 long tons were imported. The domestic production the same year was 82,350 long tons, mainly from California and Oregon.

## COBALT

| | | |
|---|---|---|
| **Cobaltite, 210** | Cubic | $CoAsS$ |
| **Smaltite, 210** | Cubic | $CoAs_2$ |

The metal cobalt is used to some extent in the manufacture of high speed tool steels and *stellite*, which is an alloy of cobalt, chromium, and tungsten. Cobalt increases the strength and elasticity of steel but lowers its ductility. Cobalt oxide is used as a blue pigment in the manufacture of glass and pottery.

Cobalt ores were mined only in Idaho in 1918. The principal source is Canada where the oxide is recovered as a by-product in the treatment of silver ores. The amount of cobalt ore and oxide imported in 1918 was 253,471 lbs.

## COPPER

| | | |
|---|---|---|
| **NATIVE COPPER, 196** | Cubic | $Cu$ |
| **CHALCOCITE, 214** | Orthorhombic | $Cu_2S$ |
| **BORNITE, 216** | Cubic | $Cu_xFe_2S_{\frac{x}{2}+3}$ |
| **CHALCOPYRITE, 215** | Tetragonal | $CuFeS_2$ |
| **Bournonite, 217** | Orthorhombic | $Pb_2Cu_2Sb_2S_6$ |
| **TETRAHEDRITE, 218** | Cubic | $M''_4R'''_2S_7$ |
| **Enargite, 219** | Orthorhombic | $Cu_3AsS_4$ |
| **CUPRITE, 232** | Cubic | $Cu_2O$ |
| **MALACHITE, 252** | Monoclinic | $CuCO_3.Cu(OH)_2$ |
| **AZURITE, 252** | Monoclinic | $2CuCO_3.Cu(OH)_2$ |
| **Brochantite, 263** | Orthorhombic | $CuSO_4.3Cu(OH)_2$ |
| **CHRYSOCOLLA, 293** | Amorphous | $CuO,SO_2,H_2O$ |

Copper is used most extensively for the transmission of electricity, and in castings and alloys. Brass consists of copper and zinc; bronze and bell metal of copper, tin, and zinc; and German silver of copper, zinc, and nickel. The hydrous copper sulphate, or blue vitriol, is used in calico printing.

Twenty-four states and territories produced copper in 1917, with Arizona, Montana, Michigan, and Utah as the leading producers. These four States contributed about 80 per cent. of the total output. The copper produced in this country is usually reported as blister copper. The following table shows the production (smelter returns), percentage of

total, copper content of the crude ore mined, and the value of gold and silver per ton recovered as by-products, in the four leading copper producing States.*

| | Production in pounds (1916) | Per cent. of total | Per cent. of Cu in ore | Value in gold and silver per ton |
|---|---|---|---|---|
| Arizona | 694,847,307 | 36.04 | 2.18 | $0.25 |
| Montana | 352,139,768 | 18.27 | 2.76 | 1.32 |
| Michigan | 269,794,531 | 13.99 | 1.08 | 0.228 |
| Utah | 232,335,950 | 12.05 | 0.90 | 0.32 |
| | | 80.35 | | |

The total output of this country during 1916 was 963,925 metric tons. Approximately the same amount of copper was produced in 1917 and 1918 as in 1916.

## FLUORINE

| | | |
|---|---|---|
| **FLUORITE, 239** | Cubic | $CaF_2$ |
| **CRYOLITE, 240** | Monoclinic | $Na_3AlF_6$ |
| **APATITE, 273** | Hexagonal | $Ca_5F(PO_4)_3$ |
| **TOPAZ, 283** | Orthorhombic | $Al_2(F,OH)_2SiO_4$ |
| **Chondrodite, 286** | Monoclinic | $[Mg(F,OH)]_2Mg_3(SiO_4)_2$ |
| **VESUVIANITE, 288** | Tetragonal | $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$ |
| **Lepidolite, 297** | Monoclinic | $(Li,K)_2(F,OH)_2Al_2Si_3O_9$ |

*Fluorite.*—About 80 per cent. of the domestic fluorite is consumed in the manufacture of basic open-hearth steel, as it gives fluidity to the slag and aids in the removal of phosphorus and sulphur. Other uses are as a flux in blast furnaces, iron foundries, silver, copper, and lead smelters, and in the manufacture of glass and enamel ware, and of hydrofluoric acid. Because of its low refractive and dispersive powers fluorite is in demand for apochromatic lenses, used in telescopes and spectroscopes. Material suitable for this work must be glass clear and free from clouds, gas bubbles, strains, and fractures. When fluorite is fused with bauxite and soda ash an artificial cryolite is produced.

In 1918 the production, which amounted to 263,817 short tons, was obtained principally from the five States, Illinois, Kentucky, Colorado, New Mexico, and Arizona; the first two being the chief producers, furnishing over 80 per cent. of the total output.

## GOLD

**NATIVE GOLD, 200** Cubic Au

Approximately 90 per cent. of the total domestic production of gold is obtained from placers and dry or silicious ores. The remaining 10 per

*According to the United States Geological Survey.

cent. is recovered from copper, lead, and zinc ores. The five leading States which in 1917 produced about 78 per cent. of the total output were:

| | |
|---|---|
| California | $20,929,400 |
| Colorado | 15,974,500 |
| Alaska | 14,671,400 |
| South Dakota | 7,372,900 |
| Nevada | 6,932,500 |

The total production in United States in 1917 was 4,051,440 fine ounces, valued at $83,750,750. The world's production the same year totaled $423,590,200. The more impotrant producing countries were:

| | |
|---|---|
| Africa | $214,614,000 |
| United States | 83,750,700 |
| Australasia | 35,945,500 |
| Russia and Finland | 18,000,000 |
| Canada | 15,200,000 |

The domestic production in 1918 was somewhat less than that indicated for 1917.

## IRON

| | | |
|---|---|---|
| **PYRRHOTITE, 207** | Hexagonal | $FeS$ |
| **PYRITE, 208** | Cubic | $FeS_2$ |
| **MARCASITE, 211** | Orthorhombic | $FeS_2$ |
| **ARSENOPYRITE, 211** | Orthorhombic | $FeAsS$ |
| **BORNITE, 216** | Cubic | $Cu_xFe_2S_{\frac{x}{2}+3}$ |
| **CHALCOPYRITE, 215** | Tetragonal | $CuFeS_2$ |
| **TETRAHEDRITE, 218** | Cubic | $M''_4R'''_2S_7$ |
| **HEMATITE, 230** | Hexagonal | $Fe_2O_3$ |
| **LIMONITE, 235** | Amorphous? | $Fe_2O_3.H_2O$ |
| **SIDERITE, 248** | Hexagonal | $FeCO_3$ |
| **WOLFRAMITE, 261** | Monoclinic | $(Fe,Mn)WO_4$ |
| **Ferberite, 261** | Monoclinic | $FeWO_4$ |
| **Melanterite, 266** | Monoclinic | $FeSO_4.7H_2O$ |
| **SPINELS, 267** | Cubic | $(Fe,Mg)(AlO_2)_2$, etc. |
| **FRANKLINITE, 270** | Cubic | $(Fe,Mn,Zn)(FeO_2)_2$ |
| **CHROMITE, 270** | Cubic | $(Fe,Cr)[(Cr,Fe)O_2]_2$ |
| **MAGNETITE, 268** | Cubic | $Fe(FeO_2)_2$ |
| **COLUMBITE, 273** | Orthorhombic | $(Fe,Mn)[(Nb,Ta)O_3]_2$ |
| **STAUROLITE, 279** | Orthorhombic | $HFeAl_5Si_2O_{13}$ |
| **EPIDOTE, 286** | Monoclinic | $Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$ |
| **Orthite, 287** | Monoclinic | $Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$ |
| **OLIVINE, 289** | Orthorhombic | $(Mg,Fe)_2SiO_4$ |
| **GARNET, 290** | Cubic | $Fe_3Al_2(SiO_4)_3$, etc. |
| **BIOTITE, 293** | Monoclinic | $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ |
| **Ilmenite, 303** | Hexagonal | $FeTiO_3$ |
| **PYROXENES, 304** | Orthorhombic, Monoclinic, and Triclinic | $(Mg,Fe)_2(SiO_3)_2$, etc. |
| **AMPHIBOLES, 309** | Orthorhombic, Monoclinic, and Triclinic | $Ca(Mg,Fe)_3(SiO_3)_4$, etc. |

The iron ores are restricted to hematite, limonite, and magnetite, with hematite by far the most important, furnishing annually about 94 per cent. of all the iron ore mined. Most of the iron ore mined is from certain well defined regions, such as the Lake Superior, the Birmingham, and the Adirondack districts. The Lake Superior district alone produced nearly 85 per cent. of the total output in 1917. The average prices of iron ore per ton for the whole United States, were $1.83 in 1915, $2.34 in 1916, $3.15 in 1917, and $3.39 for 1918.

The mine production for 1917 (in gross tons) of the various districts is shown below.

*Production in Gross Tons*

| | |
|---|---|
| Lake Superior (Minnesota, Michigan, Wisconsin) | 63,481,321 |
| Birmingham, (Alabama) | 6,187,073 |
| Chattanooga (Tennessee, Georgia, North Carolina) | 821,485 |
| Adirondack (New York) | 1,100,001 |
| Northern New Jersey and south eastern New York | 642,232 |
| Other districts | 3,056,739 |
| | 75,288,851 |

The total production in 1918 was about 70,000,000 gross tons, or about 7 per cent. less than 1917.

## LEAD

| | | |
|---|---|---|
| **GALENA, 212** | Cubic | $PbS$ |
| **Bournonite, 217** | Orthorhombic | $Pb_2Cu_2Sb_2S_6$ |
| **CERUSSITE, 251** | Orthorhombic | $PbCO_3$ |
| **ANGLESITE, 257** | Orthorhombic | $PbSO_4$ |
| **Crocoite, 258** | Monoclinic | $PbCrO_4$ |
| **Wulfenite, 259** | Tetragonal | $PbMoO_4$ |
| **PYROMORPHITE, 275** | Hexagonal | $Pb_5Cl(PO_4)_3$ |
| **Vanadinite, 275** | Hexagonal | $Pb_5Cl(VO_4)_3$ |

Galena is the most important source of lead. Large quantities of metallic lead, alloys of lead, and lead pigments are consumed annually in the trade. Some of these pigments are smelted directly from the ore, such as sublimed white lead (lead sulphate 75 per cent., lead oxide 20 per cent., and zinc oxide 5 per cent.) and sublimed blue lead (lead sulphate 50 to 53 per cent., lead oxide 38 to 41 per cent., with small amounts of lead sulphide, lead sulphite, and zinc oxide). Pigments chemically prepared from pig lead include white lead (basic carbonate), red lead, and litharge.

The lead ores from the Mississippi Valley are non-argentiferous and the lead produced from them is designated as "soft" lead, in distinction from the "hard" lead obtained from many western desilverized lead ores.

In 1918 the refined lead produced from domestic ores was 539,686 short tons, obtained principally from Missouri, Idaho, and Utah. In addition 100,008 short tons refined lead were obtained from foreign ores.

## LITHIUM

| | | |
|---|---|---|
| **TOURMALINE, 284** | Hexagonal | $M'_9Al_3(B.OH)_2Si_4O_{19}$ |
| **Lepidolite, 297** | Monoclinic | $(Li,K)_2(F,OH)_2Al_2Si_3O_9$ |
| **SPODUMENE, 308** | Monoclinic | $LiAl(SiO_3)_2$ |

The chief use of lithium is that of the hydroxide in storage batteries. The bromide and iodide are used in photography, the cyanide in Roentgen-ray experiments, and the chloride in fire works. Synthetic coal-tar products are gradually replacing the lithium salts for medicinal purposes.

The production of lithium minerals in United States is not large. In 1918 the output was 5,894 short tons, and was obtained from California and South Dakota.

## MAGNESIUM

| | | |
|---|---|---|
| **DOLOMITE, 245** | Hexagonal | $CaMg(CO_3)_2$ |
| **MAGNESITE, 246** | Hexagonal | $MgCO_3$ |
| **SPINELS, 267** | Cubic | $Mg(AlO_2)_2$, etc. |
| **TOURMALINE, 284** | Hexagonal | $M'_9Al_3(B.OH)_2Si_4O_{19}$ |
| **Chondrodite, 286** | Monoclinic | $[Mg(F,OH)]_2Mg_3(SiO_4)_2$ |
| **OLIVINE, 289** | Orthorhombic | $(Mg,Fe)_2SiO_4$ |
| **PYROPE, 292** | Cubic | $Mg_3Al_2(SiO_4)_3$ |
| **BIOTITE, 294** | Monoclinic | $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ |
| **PHLOGOPITE, 294** | Monoclinic | $(K,H)_3Mg_3Al(SiO_4)_3$ |
| **CHLORITES, 297** | Monoclinic | $H_4Mg_2Al_2SiO_9$ |
| **SERPENTINE, 297** | Orthorhombic or Monoclinic | $H_2Mg_3Si_4O_{12}$ |
| **TALC, 299** | Monoclinic? | $H_2Mg_3Si_4O_{12}$ |
| **Sepiolite, 300** | Monoclinic? | $H_4Mg_2Si_3O_{10}$ |
| **Garnierite, 300** | Unknown | $H_2(Ni,Mg)SiO_4$ |
| **PYROXENES, 304** | Orthorhombic and Monoclinic | $Mg_2(SiO_3)_2$, etc. |
| **AMPHIBOLES, 309** | Orthorhombic and Monoclinic | $(Mg,Fe)_4(SiO_3)_4$, etc. |

The uses and production of magnesite and talc only will be discussed.

*Magnesite.*—Nearly all magnesite is used in the calcined condition. Depending upon the temperature of burning, the product is either "caustic" calcined or "dead burned" magnesite. The "caustic" magnesia results from a moderate heat treatment and retains from 3 to 8 per cent. carbon dioxide. This product is chemically active, combining readily with magnesium chloride forming an oxychloride, or *Sorel* cement. This cement solidifies into an extremely hard and strong mass and is the basis of many of the sanitary flooring preparations placed upon the market under various trade names. Fillers in this cement may be cork, talc, asbestos, clay, marble dust, sand, etc. Magnesite cement floors may be laid in large areas without cracking. They take color easily and are susceptible to polish. It is claimed the surface does not pulverize or dust.

"Dead-burned" magnesite is the result of heating to incipient fusion.

The product is chemically inert. This material is employed for refractory purposes, such as brick and linings in open hearth steel and electric furnaces, and in copper converters. As a refractory substance magnesia must not only resist corrosion but in addition must possess sufficient bonding to retain its form in the furnace. In the past Austrian and Hungarian magnesites have been preferred for this purpose, as the fusion of 6 to 8 per cent. of iron contained in them increased the bonding strength. Some of the California deposits have however furnished excellent material for refractory purposes. The purer magnesite from Greece and California has been employed in the making of cement, paints, fire proof coatings, and other products.

Magnesite, raw or calcined, is also used in the manufacture of magnesium sulphate, employed in medicine and the textile industries; magnesium chloride, for making Sorel cement; and magnesium bisulphate, for disintegrating wood and dissolving the non-cellulose matter in the manufacture of wood pulp paper. The basic carbonate known as *magnesia alba* is used in fire-retarding paint and as a non-conductor of heat in coverings for steam pipes.

Metallic magnesium obtained by electrolytic or reduction processes appears to have a brilliant future, especially in aeroplane and motor construction. The metal is reported to make good castings, machines well, is about ⅓ lighter than aluminum and from two to four times as strong. Alloys of magnesium with zinc and aluminum can readily be prepared. The latter is known as *magnaleum*. Metallic magnesium is also used for scavenging alloys (removing oxygen and nitrogen) and during the war was in very great demand for military illumination in the form of shrapnel trailers, star bombs, and flare lights.

The domestic production of magnesite in 1918 was obtained from California and Washington, while Canada furnished most of the imported material.

| | Domestic production (raw) (Short tons) | Imports | |
|---|---|---|---|
| | | Raw (Short tons) | Calcined (Short tons) |
| 1916 | 154,974 | 75,345 | 9,270 |
| 1917 | 316,838 | 30,272 | 3,965 |
| 1918 | 231,605 | 5,432 | 19,049 |

*Talc and Soapstone.*—Talc and soapstone are as a rule not found together. Vermont and New York are the leading talc producing States, furnishing in 1918 nearly 85 per cent. of the total domestic output, which was 192,817 short tons. The bulk of this material was used as a white filler in the manufacture of paper. For this purpose talc is replacing china clay and English chalk. Talc is also used for foundry facing,

and in paints, rubber goods, and toilet powders. 14,218 short tons were imported in 1918, chiefly from Canada, Italy, and France. Almost the entire supply of soapstone in United States was obtained from Nelson, Albermarle, and Orange counties, Virginia. The total yield of soapstone in 1918 was 13,955 short tons, which was largely employed in the manufacture of laundry tubs, laboratory table tops, sinks, chemical hoods, fire brick, griddles, and so forth.

## MANGANESE

| | | |
|---|---|---|
| **PYROLUSITE, 227** | Orthorhombic? | $MnO_2$ |
| **MANGANITE, 234** | Orthorhombic | MnO.OH |
| **RHODOCHROSITE, 248** | Hexagonal | $MnCO_3$ |
| **Hausmannite, 253** | Tetragonal | $Mn_2MnO_4$ |
| **Psilomelane, 253** | Unknown | $MnO,BaO,H_2O$,etc. |
| **Huebnerite, 260** | Monoclinic | $MnWO_4$ |
| **WOLFRAMITE, 261** | Monoclinic | $(Fe,Mn)WO_4$ |
| **FRANKLINITE, 270** | Cubic | $(Fe,Mn,Zn)(FeO_2)_2$ |
| **COLUMBITE, 273** | Orthorhombic | $(Fe,Mn)[(Nb,Ta)O_3]_2$ |
| **SPESSARTITE, 292** | Cubic | $Mn_3Al_2(SiO_4)_3$ |
| **RHODONITE, 309** | Triclinic | $Mn_2(SiO_3)_2$ |

The economic demand for manganese is due to the importance of its alloys, especially *ferromanganese* and *spiegeleisen*. It is estimated that in recent years 14 pounds of manganese, in the form of an alloy, are added to every ton of steel produced. Ferromanganese contains 77 to 80 per cent. manganese and is used in making open hearth steel, while spiegeleisen consists of from 12 to 33 per cent. manganese and finds employment in the Bessemer process. The role of manganese is to produce a harder steel and at the same time act as a deoxidizing agent.

The oxide, $MnO_2$, is used in the manufacture of chlorine and bromine, as a drier in paints and varnishes, to color glass and pottery, and in making flint glass and dry batteries. For dry batteries the ore should contain at least 80 per cent. $MnO_2$, less than 1 per cent. iron, and under 0.05 per cent. of copper, nickel, or cobalt.

The four sources of manganese in United States are (*a*) Manganese ores which should contain 40 per cent. manganese, and less than 8 per cent. silica and 0.20 per cent. phosphorus; (*b*) Manganiferous iron ores, which contain 12 to 25 per cent. manganese; (*c*) Manganiferous silver ores, which are largely used as a flux but at intervals smelted to spiegeleisen; and (4) Manganiferous zinc residues, which are also smelted to spiegeleisen.

The domestic production of manganese ores is by no means equal to the demand, and importations from Brazil, India, and Cuba are absolutely necessary. Extensive deposits are also located in Russia. The average annual production in United States for thirty-five years (1880-1915) was 10,645 tons, but under the stimulus of high prices it is estimated that in 1918 the output was about 330,000 long tons.

PRODUCTION AND IMPORTATION OF MANGANESE ORES AND ALLOYS IN UNITED STATES, 1917–1918, IN LONG TONS

| | Production | Manganese ore | | | Ferromanganese | | Spiegeleisen | |
|---|---|---|---|---|---|---|---|---|
| | | Total imports | Imports from | | Production | Imports | Production | Imports |
| | | | India | Brazil | | | | |
| 1917 | 129,405 | 629,972 | 48,975 | 512,517 | 260,225 | 41,969 | 189,241 | 3,968 |
| 1918 | 305,869 | 491,303 | 29,275 | 345,877 | 306,076 | 26,906 | 263,861 | 1,969 |

## MERCURY

| | | |
|---|---|---|
| **CINNABAR, 215** | Hexagonal | HgS |
| **TETRAHEDRITE, 218** | Cubic | $M''_4R'''_2S_7$ |

Cinnabar is the chief source of mercury. In normal times between 30–40 per cent. of the domestic production of mercury is used in the manufacture of mercuric fulminate for explosive caps, one flask of 75 pounds making 100 to 120 pounds of detonator. Mercury is also employed in the extraction of gold by amalgamation and in scientific and electrical apparatus. The chloride (calomel) is used for medicinal purposes, and the sulphide (vermillion) and the red oxide as pigments.

In 1918 the production of mercury in United States was 32,883 flasks of 75 pounds each, valued at $3,863,752. Of this amount California contributed 22,664 flasks, Texas, 8,451 flasks, and Nevada, Oregon, Arizona and Idaho, smaller amounts.

## MOLYBDENUM

| | | |
|---|---|---|
| **Molybdenite, 205** | Hexagonal | $MoS_2$ |
| **Wulfenite, 259** | Tetragonal | $PbMoO_4$ |

At present the demand for molybdenum is not great. Its chief use is in the manufacture of special steels, being added in the form of a ferro- or manganese-molybdenum alloy (50 to 75 per cent. Mo). A nickel-molybdenum alloy is used in wire drawing. Sodium and ammonium molybdates are employed to some extent in fire-proofing fabrics, and in dyeing leather, silk, and wool. As a lubricant, molybdenite is preferable to graphite, especially for high pressure work.

The production in the United States in 1918 was equivalent to 431 short tons of metallic molybdenum. The ore as mined is of low grade, from 0.7 to 2.5 per cent. Mo, but deposits are known in Arizona, Colorado, New Mexico, Utah, California, and Montana.

## NICKEL

| | | |
|---|---|---|
| **Niccolite, 208** | Hexagonal | NiAs |
| **Garnierite, 300** | Unknown | $H_2(Ni,Mg)SiO_4$ |

To the above, nickeliferous Pyrrhotite should be added.

The demand for nickel is due largely to the importance of its alloys. The addition of from 2 to 3.50 per cent. of nickel to steel increases both its elasticity and tensile strength. *Invar*, an alloy of iron containing 36 per cent. nickel, is not affected by temperature changes and is used for scientific instruments, pendulums, and steel tapes. Other important alloys are coinage metal (copper and nickel); *German silver* (copper, zinc, and nickel); *Nichrome* (nickel and chromium) used as a substitute for platinum in electrical resistance, crucible triangles, and so forth. *Monel* is obtained by smelting the Sudbury ores without separating the metals, and consists of 67 per cent. Ni, 28 per cent. copper, and 5 per cent. other metals, mostly iron and manganese. This alloy has a tensile strength equal to that of nickel steel and is very resistive to corrosive agents. It is used for propellers, acid pumps, valves on high pressure steam lines, valve stems, pickling apparatus for sheet and tin plate, and so forth.

The world's production of nickel is obtained principally from the copper and nickel-ores of Sudbury and Cobalt, Ontario, and from the garnierite ores of New Caledonia. Since 1909 no nickel ores have been mined in the United States, although in 1918 an equivalent of 441 short tons of nickel was obtained as a by-product in the electrolytic refining of copper. Probably one-third to one-half of this amount was derived from imported ores. The imports during the same year were mainly from Canada, chiefly in the form of ore and matte, and totaled 36,603 short tons.

## NIOBIUM

**COLUMBITE, 273** Orthorhombic $(Fe,Mn)[(Nb,Ta)O_3]_2$

Niobium has no economic importance at present. Tantalum, which is nearly always present in niobium minerals, is characterized by its extreme hardness, toughness, and high melting point. It is used in the manufacture of drills, files, watch springs, pens, rectifiers for alternating currents, and electric lamp filaments. Tantalum filaments are made by pressing a mixture of the oxide and paraffine into threads which are then reduced to the metal by the passage of an electric current in a vacuum.

## NITROGEN

**SODA NITER, 241** Hexagonal $NaNO_3$

While small quantities of sodium nitrate have been found in caves and disseminated through clays in several of the western states, no deposits that can be depended upon to produce considerable amounts have been discovered in this country. Sodium nitrate is obtained almost entirely from the arid regions of northern Chile. The crude ore, containing about 25 per cent. $NaNO_3$, yields after leaching with hot water a product of 95 per cent. purity.

In normal times about 600,000 short tons of niter or Chile saltpeter

are annually imported. This is used principally as a fertilizer to promote stalk growth in plants, and also in the manufacture of nitric and sulphuric acids. In 1916, due to the unusual demands created by the war, the imports increased to 1,365,000 short tons, which were utilized approximately as follows:

| | Short tons | Approximate percentage |
|---|---|---|
| Explosives | 600,000 | 45 |
| Fertilizers | 280,000 | 20 |
| Manufacture of sulphuric acid | 85,000 | 5 |
| Miscellaneous, including stocks | 400,000 | 30 |
| | 1,365,000 | 100 |

## PHOSPHORUS

| | | |
|---|---|---|
| **Monazite, 272** | Monoclinic | $(Ce,La,Di)PO_4$ |
| **APATITE, 273** | Hexagonal | $Ca_5F(PO_4)_3$ |
| **PYROMORPHITE, 275** | Hexagonal | $Pb_5Cl(PO_4)_3$ |
| **Wavellite, 276** | Orthorhombic | $(Al.OH)_3(PO_4)_2.5H_2O$ |
| **Turquois, 276** | Triclinic | $H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$ |

Plant life requires soluble phosphates and an impure variety of apatite, known as phosphate rock, furnishes the raw material to supply this need. By treating the raw ground rock with approximately an equal weight of sulphuric acid, a superphosphate is formed which is readily assimilated by plants. Another method for rendering the phosphorus soluble consists in grinding together sodium sulphate, bituminous coal, and phosphate rock. When this dry mixture is heated in a rotary kiln under proper temperature and oxidizing conditions, a clinker is produced, which when finely ground contains 90 per cent. of the total $P_2O_5$ in a citrate-soluble form.

Under normal conditions the United States produces annually about 3,000,000 long tons of phosphate rock, but in 1918 due to the decrease in exports, the output was 2,490,760 long tons. Of this amount Florida furnished 82 per cent. and Tennessee 15 per cent. Enormous deposits of phosphate rock have been located in the western states, particularly in Idaho, Utah, Wyoming, and Montana, but the production thus far from these western localities is insignificant. At the present rate of consumption it is estimated that the western states alone could supply the world's demand for about 900 years.

## PLATINUM

| | | |
|---|---|---|
| **NATIVE PLATINUM, 195** | Cubic | Pt |

Some of the important uses of platinum are in the *contact process* for manufacturing concentrated sulphuric acid, and in the fixation of nitrogen. Because of its high fusibility and resistance to acids, platinum is in great demand in the manufacture of chemical, physical, and electrical apparatus. It is also employed in certain parts of the ignition

systems of internal combustion engines. The jewelry trade has likewise in the past consumed large amounts, estimated at 50 per cent. of the total platinum used in this country. As iridium imparts hardness to platinum, the so-called platinum used in electrical work and by jewelers is an alloy of platinum and iridium, containing from 10 per cent. to 50 per cent. of the latter element. The high price of platinum in recent years has greatly stimulated research for suitable substitutes, and alloys of palladium with gold and silver, tungsten, and molybdenum have in certain instances replaced the more expensive metal.

The disintegration of basic magnesium rocks, such as peridotite, dunite, and pyroxenite, containing disseminated platinum, has lead to the concentration of the metal in platinum placers. In normal times about 95 per cent. of the world's supply is obtained from the Ural Mountains in Russia, but it is estimated that at the rate of production before the war and with present methods of recovery, these deposits will be exhausted in about twelve years.

The United States produces a very small amount of the platinum consumed. In 1917, only 605 troy ounces of crude platinum were recovered, mainly from the placers in Alaska, California, Oregon, and Washington, although a gold-platinum-palladium mine in Clark County, Nevada, and a copper mine in Wyoming were also contributors. In addition 38,831 troy ounces of refined metals of the platinum group were obtained as by-products in the refining of copper matte and gold bullion. A considerable amount of secondary platinum is also recovered from the refining of scrap and sweeps.

The world's production of crude platinum, in troy ounces, since 1914 is given below:

| Country | 1914 | 1915 | 1916 | 1917 |
|---|---|---|---|---|
| Canada | 30 | 100 | 60 | 80 |
| Columbia | 17,500 | 18,000 | 25,000 | 32,000 |
| New South Wales, Tasmania | 1,248 | 303 | 222 | no estimate |
| Russia | 241,200 | 124,000 | 63,900 | 50,000 |
| United States | 570 | 742 | 750 | 605 |
| | 260,548 | 143,145 | 89,932 | 82,685 |

## POTASSIUM

| | | |
|---|---|---|
| **ALUNITE, 262** | Hexagonal | $K_2(Al.2OH)_6(SO_4)_4$ |
| **MICAS, 293** | Monoclinic | $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$etc. |
| **NEPHELITE, 301** | Hexagonal | $(Na,K)_8Al_8Si_9O_{34}$ |
| **LEUCITE, 313** | Orthorhombic | $K_2Al_2Si_4O_{12}$ |
| **ORTHOCLASE, 316** | Monoclinic | $KAlSi_3O_8$ |
| **MICROCLINE, 318** | Triclinic | $KAlSi_3O_8$ |
| **APOPHYLLITE, 326** | Tetragonal | $H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$ |

Potassium chloride and sulphate are used in large quantities as fertilizers. Other potassium salts are also quite essential in certain industries. Thus, caustic potash is used in the manufacture of the better grades of soap; the hydrated carbonate in cut glass, optical glass, and incandescent light bulbs; the chlorate in matches; the nitrate in black powders; the bichromate in dyeing and tanning; the cyanide as a solvent in extracting gold from ores; the ferricyanide in photography. While medicinal and other chemical uses also demand varying amounts of potassium salts.

Prior to the war United States imported over 270,000 short tons of $K_2O$. Practically the entire supply used in this country was then obtained from the famous Stassfurt deposits of Germany. With this source not available the domestic production, which in 1918 was equivalent to 54,562 short tons of $K_2O$ valued at $21,437,300, was derived from:

| | |
|---|---|
| Natural salts or brines | 39,716 |
| Alunite | 2,621 |
| Dust from cement mills and blast furnaces | 1,779 |
| Kelp | 4,804 |
| Wood ashes | 1,213 |
| Distillery waste (molasses) | 3,467 |
| Other sources | 962 |
| | 54,562 |

The imports in 1918 amounted to only 7,957 short tons of $K_2O$, valued at $8,907,836.

## SILICON

| | | |
|---|---|---|
| **QUARTZ, 220** | Hexagonal | $SiO_2$ |
| **OPAL, 232** | Amorphous | $SiO_2.xH_2O$ |

Silicon is also an essential constituent of all silicates.

The greatest demand for quartz comes from the building trade. The value of sandstone (including quartzite) sold in United States in 1917 was $5,512,421, which represented 6.7 per cent. of the total value of all stone sold that year. The three leading states which contributed nearly 70 per cent. of the total value of sanstone were Pennsylvania, Ohio, and New York.

Some varieties of quartz, as well as opal, are prized as gems and the value of their output in 1918 was estimated at $21,515.

## SILVER

| | | |
|---|---|---|
| **NATIVE SILVER, 199** | Cubic | Ag |
| **Argentite, 213** | Cubic | $Ag_2S$ |
| **Proustite, 217** | Hexagonal | $Ag_3AsS_3$ |
| **Pyrargyrite, 217** | Hexagonal | $Ag_3SbS_3$ |
| **TETRAHEDRITE, 218** | Cubic | $M''_4R'''_2S_7$ |
| **Cerargyrite, 238** | Cubic | AgCl |

The four most important sources of silver in United States, which in 1917 furnished over 98 per cent. of the total output, were dry or siliceous ores (30.4 per cent.), copper ores (28.8 per cent.), lead ores (27 per cent.), and lead-zinc ores (12.2 per cent.)

Siliceous ores are those consisting mainly of quartz with small amounts of gold and silver. Some of the chief deposits of this type are at Tonopah, Nevada; San Juan, Leadville, and Aspen, Colorado; and in Granite, Jefferson, and Silver Bow counties, Montana. The important silver bearing copper ores are found at Butte, Montana; in the Bingham and Tintic districts, Utah; and at Bisbee and Jerome, Arizona. Deposits of argentiferous galena are mined in the Coeur d'Alene district, Idaho; Bingham and Tintic districts, Utah; and at Aspen and Leadville, Colorado.

The total domestic production in 1917 was 71,740,362 ounces valued at $59,078,100, of which the following six States were the most important producers.

| | |
|---|---|
| Montana | 14,555,034 ounces |
| Utah | 13,360,905 ounces |
| Idaho | 11,402,542 ounces |
| Nevada | 11,217,654 ounces |
| Colorado | 7,291,495 ounces |
| Arizona | 6,962,257 ounces |

The production in 1918 amounted 67,879,206 ounces.

## SODIUM

| | | |
|---|---|---|
| **HALITE, 236** | Cubic | $NaCl$ |
| **CRYOLITE, 240** | Monoclinic | $AlF_3.3NaF$ |
| **SODA NITER, 241** | Hexagonal | $NaNO_3$ |
| **NEPHELITE, 301** | Hexagonal | $(Na,K)_8Al_8Si_9O_{34}$ |
| **Cancrinite, 302** | Hexagonal | $H_6(Na_2,Ca)_4(NaCO_3)_2Al_8Si_9O_{36}$ |
| **Sodalite, 303** | Cubic | $Na_4Al_2(AlCl)(SiO_4)_3$ |
| **Lazurite, 303** | Cubic | $(Na_2,Ca)_2Al_2[Al(NaSO_4,NaS_3,Cl)](SiO_4)_3$ |
| **Pectolite, 307** | Monoclinic | $(Ca,Na_2)_2(SiO_3)_2$ |
| **ALBITE** and **PLAGIOCLASES, 319** | Triclinic | $NaAlSi_3O_8$, etc. |
| **SCAPOLITE, 322** | Tetragonal | $Ca_4Al_6Si_6O_{25}$, etc. |
| **Natrolite, 324** | Orthorhombic | $Na_2Al(AlO)(SiO_3)_3.2H_2O$ |
| **ANALCITE, 325** | Cubic | $Na_2Al_2(SiO_3)_4.2H_2O$ |
| **STILBITE, 326** | Monoclinic | $(Ca,Na_2)Al_2Si_8O_{16}.6H_2O$ |

Halite or salt, as produced in this country, is of two types, either rock salt or brine salt. Rock salt occurs in beds and is mined by means of shafts in a manner similar to that of coal. The output of rock salt in 1918 was 1,683,941 short tons. Brine salt may be made from natural or artificial brines. In the majority of cases fresh water is forced through drill holes to the salt beds and the artificial brine then pumped to the surface. The salt is obtained by the evaporation of the brine by either

solar or vacuum pan processes. Other chemical products produced from the brine include salt cake, soda ash, caustic soda, sodium bicarbonate, sodium acetate, sodium chlorate, sodium phosphate, *Glauber's* salt, calcium chloride, chlorine, and hydrochloric acid.

United States furnishes practically all the salt consumed in this country and the supply seems inexhaustible. In the single State of New York an area of approximately 2000 square miles is underlain with salt, the thickness of which varies from 8 to 318 feet.

The domestic production in 1918 was 7,238,744 short tons, (equivalent to over 50,000,000 bbl. of 280 lbs.), which was an increase of 3.7 per cent. in quantity and 35.1 per cent. in value over the production in 1917. Although fifteen States reported a production, the four leading producers were:

| | |
|---|---|
| Michigan | 2,403,125 short tons |
| New York | 2,130,530 short tons |
| Ohio | 1,089,887 short tons |
| Kansas | 819,504 short tons |

## STRONTIUM

| | | |
|---|---|---|
| **STRONTIANITE, 250** | Orthorhombic | $SrCO_3$ |
| **CELESTITE, 255** | Orthorhombic | $SrSO_4$ |

Before the war the entire supply of celestite and strontianite was imported from Germany, England, and Sicily. With the curtailment of shipments from those sources domestic deposits of a commercial nature were located in southern California, Washington, and Texas. The carbonate is the more valuable ore as it can be easily converted into the various salts, but the sulphate is much more abundant. In 1917 about 4,035 short tons of strontium ore were mined in the United States, of which about 10 per cent. was strontianite and the balance celestite. Strontium salts are used in pyrotechnics, for the recovery of sugar in beet-sugar refineries, and in medicine. In 1918 the production fell to 400 short tons.

## SULPHUR

| | | |
|---|---|---|
| **NATIVE SULPHUR. 193** | Orthorhombic | S |
| **Lazurite, 303** | Cubic | $(Na_2,Ca)_2Al._2[Al(NaSO_4,NaS_3,Cl](SiO_4)_3$ |

Sulphur is also an essential constituent of sulphides and sulphates.

Deposits of native sulphur in Louisiana and Texas furnish more than 99 per cent. of the entire output of this country. Occurrences of minor importance are known in Wyoming, Utah, Nevada, California, Colorado, and Oregon. The production of sulphur in 1918 was 1,353,525 long tons. Under normal conditions the bulk of the sulphur employed in the manufacture of sulphuric acid is obtained from pyrite, and copper and zinc

bearing sulphides which are burned to sulphur dioxide. In 1918 the domestic production of pyrite was 455,432 long tons, while 496,792 tons were imported, mainly from Spain and Portugal. In the manufacture of paper it is estimated that one-eighth of a ton of sulphur is used for each ton of sulphite pulp produced.

It is estimated that in 1917 the production of sulphuric acid consisted of 5,967,551 tons of a strength of 50° Baume (62.18 per cent. $H_2SO_4$) and of 759,039 tons of a strength higher than 66° Baume (93.19 per cent. $H_2SO_4$). The 50° acid is used largely in the manufacture of fertilizers, sulphate of ammonia, and alum; while the more concentrated acid is employed in the steel industry (for pickling purposes), for the purification of petroleum, and in the manufacture of explosives.

## TIN

| | | |
|---|---|---|
| **CASSITERITE, 226** | Tetragonal | $SnO_2$ or $SnSnO_4$ |

While cassiterite is rather widely disseminated, in a few places only are the occurrences of commercial importance. The production in the United States is insignificant when compared with the consumption of the metal, which under normal condition is approximately 50,000 tons annually. Deposits have been worked intermittently in South Dakota, Texas, North, and South Carolina. Alaska is at present a more consistent producer and in 1918 its output was equivalent to 68 tons of metallic tin.

The World's chief sources of tin ore are the Malay States, Bolivia, Australia, and Cornwall, England. In 1917 the production was distributed as follows:

| | Short tons of metallic tin |
|---|---|
| Malaya States | 49,000 |
| Bolivia | 29,300 |
| Banka | 14,000 |
| Siam | 9,400 |
| China | 9,000 |
| Australia | 6,000 |
| Nigeria | 6,000 |
| Billiton | 5,500 |
| Cornwall | 4,600 |
| South Africa | 2,000 |
| Other countries | 2,000 |

In 1918 the world's production was slightly less than that indicated above.

## TITANIUM

| | | |
|---|---|---|
| **RUTILE, 224** | Tetragonal | $TiO_2$ or $TiTiO_4$ |
| **Ilmenite, 303** | Hexagonal | $FeTiO_3$ |
| **TITANITE, 323** | Monoclinic | $CaSiTiO_5$ |

The demand for titanum is not very great. Rutile and ilmenite

are both used in making *ferrotitanium* which when added to Bessemer steel serves as a deoxidizing agent and increases its tensile strength. Rutile is also the source of titanium for *cuprotitanium* used in brass and other copper bearing alloys. Titanium-aluminum bronze, which is extremely resistant to the action of sea water and chemical liquors, possesses physical properties equalling those of phosphor and manganese bronze, although it is considerably lighter than either.

In 1918 the Virginia mines reported a production of 261 short tons of rutile valued at $39,150. The rutile carries about 95 per cent. of $TiO_2$. In the concentration process a considerable quantity of ilmenite is also recovered as a by-product.

## TUNGSTEN

| | | |
|---|---|---|
| **Scheelite, 259** | Tetragonal | $CaWO_4$ |
| **Huebnerite, 260** | Monoclinic | $MnWO_4$ |
| **WOLFRAMITE, 261** | Monoclinic | $(Fe,Mn)WO_4$ |
| **Ferberite, 261** | Monoclinic | $FeWO_4$ |

While in foreign countries wolframite is the most important ore of tungsten, in the United States both scheelite and ferberite surpass it in importance. Over 90 per cent. of the tungsten mined is converted into ferro-alloys and tungsten steels. American high-speed tool steels, which are capable of holding their temper at a red heat, contain about 18 per cent. tungsten, 4.5 per cent. chromium, and 0.6 per cent. vanadium. In some cases 3 to 5 per cent. of cobalt is also added. These steels are also used for armor plate and projectiles. Tungsten alloys readily with many metals and some of these have been proposed as substitutes for platinum, particularly a tungsten-molybdenum alloy for dental work.

The production of tungsten ores in the United States in 1918 was equivalent to 5,041 short tons of concentrates containing 60 per cent. $WO_3$ valued at $6,802,000. The imports during 1918 were 11,750 tons of ore valued at $11,409,237. The domestic production is obtained mainly from Boulder Country, Colorado, and from the Atolia district, California. Important foreign deposits are located in Burma, Portugal, Australia, Bolivia, and Argentina.

## URANIUM

| | | |
|---|---|---|
| **Uraninite, 262** | Cubic | $UO_3,UO_2,PbO$, etc. |
| **Carnotite, 277** | Orthorhombic | $K_2O.2UO_3.V_2O_5.3H_2O$? |

*Ferro-uranium* is used in high speed steel and *aluminum-uranium* in non-ferrous alloys. In special steels a small percentage of uranium may be substituted for tungsten, while in non-ferrous alloys it is beneficial because of its deoxidizing properties. Uranium compounds are employed to some extent in coloring glass yellow with a green reflex; in photography;

in the ceramic industry to impart yellow, brown, gray, and velvety tints; and as a mordant for silk and wool. Radium is sometimes recovered from uranium minerals. The amount present is extremely small, about one-third of a milligram of radium in one kilogram (2.2046 lbs.) of uranium. When uranium is used as an illuminant the radium salt is usually mixed with artificial zinc sulphide and some cementing material, such as amyl acetate. The alpha rays given off by the radium salt strike the particles of zinc sulphide and cause them to glow.

Carnotite from southwestern Colorado and southeastern Utah is the chief domestic source of uranium compounds and in 1918 the output was equivalent to 105.5 tons of $U_3O_8$ containing 27.1 grams of radium.

## VANADIUM

| | | |
|---|---|---|
| **Vanadinite, 275** | Hexagonal | $Pb_5Cl(VO_4)_3$ |
| **Carnotite, 277** | Orthorhombic | $K_2O.2UO_3.V_2O_5.3H_2O$? |
| **Roscoelite, 296** | Monoclinic | $H_8K_2(Mg,Fe)(Al,V)_4(SiO_3)_2$? |

The most important use of vanadium is in the manufacture of special steels, where it not only removes the objectionable elements oxygen and nitrogen, but the small amount (about 0.22 per cent.) remaining in the steel increases its tensile strength and resistance to shock. Vanadium steel is extensively used for locomotive and automobile cylinders, pistons and bushings, and also for high speed tools, die blocks, and so forth. Because of their strength and toughness vanadium bronzes are suitable for trolley wheels and bronze gears. Vanadium compounds are employed in ceramics to produce a golden glaze, in the preparation of indelible ink, for fixing aniline black on silk, and as a catalytic agent in the manufacture of sulphuric acid.

About 80 per cent. of the world's supply of vanadium is derived from the sulphide ($VS_4$?), *patronite*, which occurs in quantity only at Minasragra, Peru. The chief domestic source of the metal and its compounds is the vanadium mica, roscoelite. Subordinate amounts are obtained from carnotite and vanadinite. Roscoelite is mined principally in the vicinity of Placerville and Vanadium, San Miguel County, Colorado, where it occurs in small bands in, and disseminated throughout, a greenish sandstone. The rock averages from 1 to 1½ per cent. vanadium. In 1918 the equivalent of 276 tons of vanadium was produced in the United States.

## ZINC

| | | |
|---|---|---|
| **SPHALERITE, 205** | Cubic | ZnS |
| **TETRAHEDRITE, 218** | Cubic | $M''_4R'''_2S_7$ |
| **Zincite, 228** | Hexagonal | ZnO |
| **SMITHSONITE, 247** | Hexagonal | $ZnCO_3$ |
| **FRANKLINITE, 270** | Cubic | $(Fe,MnZn)(FeO_2)_2$ |
| **HEMIMORPHITE, 280** | Orthorhombic | $H_2Zn_2SiO_5$ |
| **Willemite, 289** | Hexagonal | $Zn_2SiO_4$ |

In normal times about 60 per cent. of the spelter (zinc) output is used for galvanizing, 20 per cent. in making brass, 11 per cent. is rolled into sheet zinc, 1 per cent. for desilverizing lead, and 8 per cent. for all other purposes. Zinc dust is used for precipitating gold from cyanide solutions, and some of the zinc compounds are employed as pigments. The four white pigments involving the use of zinc are, zinc oxide (zinc white), leaded zinc oxide, zinc-lead oxide, and lithopone. Lithopone is a mixture obtained by chemical precipitation of zinc sulphide and barium sulphate.

The chief zinc producing regions in the United States are:

Joplin district (Missouri, Kansas, Oklahoma) producing about 25%
Franklin Furnace District (New Jersey) producing about 20%
Butte District (Montana) producing about 20%
Mississippi Valley District (Wis., Iowa, Ill.) producing about 5 to 10%
Leadville district (Colorado) producing about 5 to 10%
Coeur d'Alene district (Idaho) producing about 5 to 10%

In 1913 the domestic production of zinc was 337,252 short tons, which in 1918 was increased to 492,405 short tons. The production in 1915, in terms of the metal, of the more important producing states, together with the quantity of recoverable zinc contained in the crude ore is given below.

| | | | |
|---|---|---|---|
| Missouri.... | 136,300 short tons; 1.3% | Wisconsin..... | 41,403 short tons; 2.1% |
| New Jersey.. | 116,618 short tons; 15.8% | Idaho..... | 35,077 short tons; 10.1% |
| Montana.... | 93,573 short tons; 13.2% | Tennessee..... | 16,461 short tons; 3.1% |
| Colorado.... | 52,297 short tons; 19.5% | Kansas..... | 14,365 short tons; 2.0% |

The recoverable zinc content of the ores varied from 32.8 per cent. in Nevada to 1.3 per cent. in Missouri, giving an average for the entire United States of 2.7 per cent.

## ZIRCONIUM

**ZIRCON, 225** Tetragonal $ZrSiO_4$

The uses of zirconium and its compounds are very limited. The addition of small amounts of zirconium to steels, brass, and copper is claimed to secure sound castings and to increase their strength and resistance to acids. *Cooperite* is an alloy of zirconium and nickel, and is very resistant to acids and alkalis. It is also recommended for use in the manufacture of machine and cast tools. As its heat conductivity is higher than for other high speed metals the cutting efficiency is increased. Increasing the amount of zirconium in the alloy increases the hardness but decreases the melting point and tensile strength. Cooperite is claimed to be self-hardening and no tempering is necessary. The oxide, zirconia, glows intensely when heated and therefore has been used for coating the lime and magnesia pencils used in the Drummond or "lime" light. The filaments of the Nernst lamp consist mainly of zirconia with

variable amounts of yttria, erbia, thoria, and ceria. The oxide is also used as an opacifier in enamel ware, as a permanent white pigment not affected by acids or alkalies, as a polishing powder, and for refractory purposes.

The chief source is the oxide, baddeleyite, found in quantity in Minas Geraes, Brazil. The mineral zircon was formerly an important source.

## GLOSSARY

This glossary contains all the important terms used in the descriptive and determinative portions of the book. See the index for page references to other terms.

**Acicular**—needle-like.

**Acute**—sharply pointed.

**Adamantine luster**—like that of the diamond, or oiled glass.

**Aggregate**—mass, cluster, group.

**Alkaline taste**—like that of soda.

**Allochromatic**—having a color which is not an inherent property of the mineral, but due to pigments, inclusions, or other impurities, hence, variable.

**Alluvial**—relating to deposits made by flowing water.

**Amorphous**—devoid of crystallinity.

**Amygdaloid**—igneous rock containing small cavities, which are filled entirely, or in part, with minerals of secondary origin.

**Arborescent**—branching, tree-like.

**Argillaceous**—clay-like odor.

**Asterism**—a star-like effect seen in either transmitted or reflected light.

**Astringent taste**—causing contraction or puckering.

**Basal**—parallel to the basal pinacoid.

**Basalt**—basic igneous rock, dark and compact.

**Bipyramid**—two pyramids placed base to base.

**Bisphenoid**—four-sided form of the tetragonal system, each face being an isosceles triangle.

**Bituminous**—odor due to the presence of bitumen or other organic matter.

**Bladed**—elongated and flattened, like a knife blade.

**Botryoidal**—closely united spherical masses, resembling a bunch of grapes.

**Brachypinacoid**—form with two faces in the orthorhombic or triclinic systems, parallel to the brachy and vertical axes.

**Brittle**—crumbles under knife or hammer, cannot be cut into slices.

**Capillary**—hair- or thread-like.

**Carbonatization**—formation of carbonates.

**Cellular**—porous, like a sponge.

**Chatoyant**—having a changeable, undulating, or wavy color or luster.

**Clastic**—made up of fragments.

**Clay**—fine, soft, aluminous sediments that are plastic.

**Cleavable**—capable of splitting in definite directions.

**Cleavage**—property of many crystalline substances of breaking or splitting in definite directions, yielding more or less smooth surfaces.

**Clinopinacoid**—form with two faces in the monoclinic system, parallel to the clino and vertical axes.

**Columnar**—long thick fibers, often parallelly grouped.

**Compact**—closely or firmly united.

**Complex crystals**—highly modified, having many crystal forms or faces.

**Concentric**—spherical layers about a common center, similar to layers of an onion.

**Conchoidal**—curved, shell-like.

**Concretion**—rounded mass formed by accumulation about a center.

**Concretionary**—formed as a concretion.

**Confused**—indistinct, jumbled together.

**Conglomerate**—sedimentary rock, composed of rounded fragments, coarse or fine.

**Contact mineral**—formed under the influence of an igneous intrusion.

**Crested**—tabular crystals arranged in ridges.

**Cruciform**—in the form of a cross, cross-shaped.

**Cryptocrystalline**—finely crystalline, revealed only under the microscope.

**Crystal**—substance bounded, entirely or partially, by natural plane surfaces.

**Crystalline**—having crystal structure, but without definite geometrical form.

**Crystallization**—process of solidification in the form of well developed crystals, or in crystalline masses.

**Crystallography**—study of crystal forms and properties.

**Cubical**—with the form of a cube.

**Cyclic**—repeated twinning yielding circular forms.

**Dendritic**—branching, fern-like.

**Diaphaneity**—ability to transmit light.

**Dichroism**—property of exhibiting different colors by transmitted light when viewed in two perpendicular directions.

**Disseminated**—scattered through a substance.

**Divergent**—radiating from a center.

**Dodecahedral**—pertaining to the rhombic dodecahedron, a form with twelve faces in the cubic system.

**Domatic**—relating to a dome, a horizontal prism.

**Drusy**—rough surface due to a large number of small, closely crowded crystals.

**Ductile**—capable of being drawn into wire. Ductile substances are also malleable and sectile.

**Dull luster**—not bright or shiny.

**Earthy**—without luster, dull.

**Efflorescence**—thin crust or coating, often powdery.

**Elastic**—resumes original position when displaced.

**Eruptive rock**—formed by the solidification of a surface flow of molten rock. Often used as a synonym of igneous.

**Etched**—corroded.

**Felted**—fibers closely matted.

**Ferruginous**—containing iron.

**Fetid**—emitting an offensive odor.

**Fibrous**—consisting of slender fibers or filaments.

**Fissure**—crack or crevice.

**Flexible**—capable of bending without breaking, and does not resume original position when the force is removed.

**Fluorescence**—property of emitting light when exposed to electrical discharges, or when heated.

**Folia**—having the form of thin plates or leaves.

**Foliated**—in plates or leaves which separate easily.

**Fossiliferous**—containing or composed of fossils.

**Fracture**—refers to surface obtained when breaking in a direction other than parallel to cleavage or parting.

**Friable**—easily crumbled or reduced to powder.

**Furrowed**—deeply striated, grooved.

**Gangue**—associates of more valuable minerals or ores.

**Garlic**—odor observed when arsenic minerals are heated.

**Globular**—spherical or nearly so.

**Gneiss**—laminated or foliated metamorphic rock consisting usually of quartz, feldspar, and mica.

**Granite**—coarsely crystalline igneous rock, consisting usually of quartz, feldspar (orthoclase), and mica or hornblende.

**Granular**—consisting of closely packed grains, either coarse or fine.

**Guano**—excrement of sea fowl.

**Habit**—development or form of crystals.

**Hackly**—rough surface, covered with sharp points.

**Hardness**—resistance offered to abrasion or scratching.

**Hemimorphic**—having different planes about the two ends of a crystallographic axis.

**Hexoctahedron**—form of the cubic system having forty-eight faces.

**Hopper shaped**—cavernous and tapering, square funnel shaped.

**Hydration**—combining chemically with water.

**Hygroscopic**—property of absorbing moisture from the atmosphere.

**Idiochromatic**—minerals with a constant color, an inherent property.

**Igneous rock**—one formed by the solidification of a molten mass from within the earth.

**Impregnated**—finely disseminated and intimately mixed with rock.

**Impressed**—marked by pressure, indented.

**Inclusion**—foreign material enclosed within a mineral.

**Incrustation**—crust or coating on another substance.

**Inelastic**—not elastic.

**Interlaced**, **Interwoven**—intertwined, confused.

**Iridescence**—showing play of colors, usually due to thin film or coating.

**Isochromatic**—lines or sections possessing the same color.

**Kimberlite**—altered, very basic igneous rock, consisting essentially of serpentine, olivine, augite, pyrope; sometimes diamond-bearing.

**Lamellæ**, **Laminæ**—small, thin plates or layers, curved or straight.

**Lamellar**—consisting of lamellæ or laminæ.

**Lava**—molten rock, especially surface flows; also applied to the solidified product.

**Lenticular**—lens-shaped.

**Limestone**—rock composed essentially of calcium carbonate, calcite.

**Luster**—manner in which the surface reflects light.

**Macropinacoid**—form with two faces in the orthorhombic or triclinic systems, parallel to the macro and vertical axes.

**Macroscopic**—visible to the unaided eye, opposed to microscopic.

**Malleable**—capable of being flattened by hammering.

**Mammillary**—rounded mass, larger than that of a grape.

**Marble**—recrystallized limestone or dolomite; may also include other limestones susceptible to a polish, and serpentine.

**Massive**—without definite crystal form; either crystalline or amorphous.

**Meager**—rough touch.

**Metallic luster**—simulating a metal and exhibited by minerals which are opaque or nearly so, and quite heavy.

**Metalloidal**—having the appearance of a metal.

**Metamorphic rock**—one that has been altered by heat, pressure, liquids, or gases, so as to render its texture either crystalline or schistose.

**Meteorite**—mass of stone or iron which has fallen to the earth from outer space.

**Micaceous**—composed of very thin plates or scales, like those of mica.

**Mimicry**—imitation of forms of a higher symmetry by those of lower grade of symmetry, usually the result of twinning.

**Modified, highly**—consisting of a large number of crystal forms or faces.

**Monochromatic**—homogeneous light of a definite wave-length.

**Mottled**—spotted.

**Multi-colored**—having many colors.

**Neolithic**—later stone age, that of smooth or polished stone implements.

**Nodular**, **Nodule**—rounded mass of irregular shape.

**Nugget**—rounded, irregular lump, especially of a metal.

**Ocherous**—earthy, and usually red, yellow, or brown in color.

**Octahedral**—pertaining to the octahedron, eight-sided form of the cubic system.

**Oolitic**—rounded particles the size of fish-eggs.

**Opalescent**—with milky or pearly reflections.

**Opaque**—will not transmit light even through thin layers or edges.

**Orthopinacoid**—form with two faces in the monoclinic system, parallel to the ortho and vertical axes.

**Oxidation**—combing chemically with oxygen.

**Paleolithic**—earlier stone age, that of rough stone implements.

**Parameters**—linear intercepts of a crystal face on the crystallographic axes.

**Parting**—false cleavage, usually the result of twinning.

**Pearly**—similar to the luster of the mother of pearl.

**Peat**—dark brown to black substance, formed by the partial decomposition of vegetable tissue in marshes.

**Pegmatite**—very coarse grained acid igneous rock, consisting essentially of quartz, feldspar, and mica.

**Peridotite**—very basic igneous rock, composed largely of olivine and augite or hornblende.

**Phanerocrystalline**—crystals or coarsely crystalline.

**Phonolite**—compact extrusive rock, consisting essentially of orthoclase, nephelite, and pyroxene.

**Pinacoidal**—relating to forms with two planes, parallel to two or more crystallographic axes.

**Pisolitic**—composed of small, rounded masses, the size of peas.

**Pitchy**—resembling pitch.

**Placers**—sands and gravels containing minerals of economic importance.

**Plastic**—capable of being molded or shaped.

**Plates**—broad, relatively thin masses.

**Platy**—consisting of plates.

**Plumose**—feathery.

**Pocket**—cavity in a rock, often filled with minerals.

**Polysynthetic**—consisting of thin lamellæ due to repeated twinning.

**Prismatic**—elongated parallel to one of the crystallographic axes, usually the vertical axis.

**Pseudo**—false.

**Pseudomorph**, **Pseudomorphous**—possessing the geometrical form of another mineral.

**Pungent**—sharp, biting.

**Pyramidal**—pertaining to the pyramid, a form which usually intersects three crystallographic axes.

**Pyritohedron**—form of the cubic system with twelve, five-sided faces.

**Rectangular**—intersecting at 90°.

**Reduction**—loss of oxygen chemically.

**Refraction, double**—yielding two refracted rays.

**Reniform**—large, rounded masses, kidney-shaped.

**Resinous**—luster of resin, greasy.

**Reticulated**—fibers crossing like a net.

**Rhombic**—diamond-shaped.

**Rhombohedral**—relating to the rhombohedron, a form of the hexagonal system, with six faces intersecting at angles other than 90°.

**Rosette**—simulating a rose.

**Saline**—salty.

**Sandstone**—sedimentary rock consisting of consolidated sand.

**Scalenohedral**—relating to the scalenohedron, a twelve-sided form of the hexagonal system, each face being a scalene triangle..

**Scaly**—consisting of scales.

**Schiller**—peculiar bronze-like luster.

**Schist**—metamorphic rock with foliated or parallel structure, splitting easily along certain planes.

**Seam**—narrow vein.

**Sectile**—capable of having slices cut off.

**Semi-opaque**—between opaque and transparent.

**Shale**—laminated sedimentary rock, consisting of hardened muds, silts, or clays.

**Sheaf-like**—resembling a sheaf of wheat.

**Silky**—luster of silk, due to fibrous structure.

**Skeletal**—pertaining to crystals with incomplete development of their faces, often with cavernous appearance.

**Slate**—dense, fine grained metamorphic rock, which splits easily into broad, thin layers or sheets.

**Splendent**—very bright by reflected light.

**Splintery**—breaking into splinters.

**Stalactitic**—cylindrical or conical masses resembling icicles.

**Stalky**—consisting of long, stout fibers.

**Stellate**—radiating from a center producing star-like forms.

**Streak**—color of fine powder, usually obtained by rubbing the mineral on unglazed porcelain.

**Subadamantine**—imperfectly adamantine.

**Subconchoidal**—imperfectly conchoidal.

**Sublimation**—direct solidification from a vapor.

**Submetallic**—imperfectly metallic.

**Syenite**—granular igneous rock, commonly consisting of orthoclase, and hornblende or biotite.

**Tabular**—flat, tablet-like.

**Tarnish**—thin film formed on the surface when exposed to air and different in color from that of the fresh fracture.

**Terminations**—faces on the end of a crystal.

**Tetragonal trisoctahedron**—form of the cubic system with twenty-four trapezohedral faces.

**Tetrahedral**—pertaining to the tetrahedron, a four-sided form of the cubic system.

**Tetrahexahedron**—form of the cubic system with twenty-four triangular faces.

**Tough**—not easily broken.

**Translucent**—when light passes through, but objects can not be seen distinctly.

**Transparency**—refers to the amount of light passing through a substance.

**Transparent**—when sufficient light passes through the substance so that objects may be distinctly seen.

**Trap**—dark, basic, fine grained igneous rock.

**Trichroism**—property of exhibiting different colors by transmitted light when viewed in three perpendicular directions.

**Trillings**—intergrowth of three crystals in a symmetrical manner.

**Twinned**—crystals consisting of more than one individual, arranged in a definite manner.

**Twins**—Symmetrical intergrowth of two crystals.

**Variegated**—with different colors.

**Vein**—crack or fissure, partially or completely filled with mineral matter.

**Vitreous luster**—like that of glass.

**Warty**—small, rounded masses resembling warts.

**Waxy**—luster of wax.

**Zonal**—in zones or layers.

---

## TABULAR CLASSIFICATION SHOWING ELEMENTS OF SYMMETRY AND THE SIMPLE FORMS OF THE THIRTY-TWO CLASSES OF CRYSTALS

(Pages 372 to 378).

## Tabular Classification Showing the Elements of Symmetry and the Simple Forms of the Thirty-two Classes of Crystals

### 1. Cubic System

| Class | Symmetry: Planes: Axial | Symmetry: Planes: Diagonal | Symmetry: Axes: ● | Symmetry: Axes: ▲ | Symmetry: Axes: ⬬ | Symmetry: Center | Forms: $a:a:a$ {111} | Forms: $a:a:\infty a$ {110} | Forms: $a:\infty a:\infty a$ {100} | Forms: $a:a:ma$ {$hhl$} | Forms: $a:ma:ma$ {$hll$} | Forms: $a:ma:\infty a$ {$hko$} | Forms: $a:na:ma$ {$hkl$} | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1. Hexoctahedral** (*Holohedrism*)[1] | 3 | 6 | 3 | 4 | 6 | 1 | Octahedron (8)[2] | Rhombic Dodecahedron (12) | Hexahedron (6) | Trigonal Trisoctahedrons (24) | Tetragonal Trisoctahedrons (24) | Tetrahexahedrons (24) | Hexoctahedrons (48) | Galena $PbS$ |
| **2. Hextetrahedral** (*Tetrahedral Hemihedrism*) | – | 6 | – | 4 (*Polar*) | 3 | – | (±) Tetrahedrons (4) | Rhombic Dodecahedron (12) | Hexahedron (6) | (±) Tetragonal Tristetrahedrons (12) | (±) Trigonal Tristetrahedrons (12) | Tetrahexahedrons (24) | (±) Hextetrahedrons (24) | Tetrahedrite $(Cu_2, Fe, Zn)_4(AS, Sb)_2S_7$ |
| **3. Dyakisdodecahedral** (*Pyritohedral Hemihedrism*) | 3 | – | – | 4 | 3 | 1 | Octahedron (8) | Rhombic Dodecahedron (12) | Hexahedron (6) | Trigonal Trisoctahedrons (24) | Tetragonal Trisoctahedrons (24) | (±) Pyritohedrons (12) | (±) Dyakisdodecahedrons (24) | Pyrite $FeS_2$ |
| **4. Pentagonal Icositetrahedral** (*Plagihedral Hemihedrism*) | – | – | 3 | 4 | 6 | – | Octahedron (8) | Rhombic Dodecahedron (12) | Hexahedron (6) | Trigonal Trisoctahedrons (24) | Tetragonal Trisoctahedrons (24) | Tetrahexahedrons (24) | ($r$, $l$) Pentagonal Icositetrahedrons (24) | Sal Ammoniac $NH_4Cl$ |
| **5. Tetrahedral Pentagonal Dodecahedral** (*Tetartohedrism*) | – | – | – | 4 (*Polar*) | 3 | – | (±) Tetrahedrons (4) | Rhombic Dodecahedron (12) | Hexahedron (6) | (±) Tetragonal Tristetrahedrons (12) | (±) Trigonal Tristetrahedrons (12) | (±) Pyritohedrons (12) | ($\pm r$, $\pm l$) (Tetrahedral) Pentagonal Dodecahedrons (12) | Sodium Chlorate $NaClO_3$ |

[1] Although the older ideas of holohedrism and hemihedrism have not been used in the development of crystallographic forms, pages 1 to 81, for the sake of completeness, however, these older terms are also given in this classification of the thirty-two classes of symmetry.

[2] The figures after the names of the forms indicate the number of faces they possess.

| Class | Symmetry: Planes: Horizontal: Axial | Symmetry: Planes: Vertical: Axial | Symmetry: Planes: Vertical: Intermediate | Symmetry: Axes: Vertical: ● | Symmetry: Axes: Vertical: ▲ | Symmetry: Axes: Horizontal: ⬬ | Symmetry: Center | Forms: $o$: $\infty a:a:mc$ {10$\bar{1}$1} | Forms: $2a:2a:a:mc$ {$hh\bar{2}hl$} | Forms: $na:pa:a:mc$ {$hi\bar{k}l$} | Forms: $a:\infty a:a:\infty c$ {10$\bar{1}$0} | Forms: $2a:2a:a:\infty c$ {11$\bar{2}$0} | Forms: $na:pa:a:\infty c$ {$hi\bar{k}o$} | Forms: $\infty a:\infty a:\infty a:c$ {0001} | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **6. Dihexagonal Bipyramidal** (*Holohedrism*) | 1 | 3 | 3 | 1 | – | 3+3 | 1 | Hexagonal Bipyramids First order (12) | Hexagonal Bipyramids Second order (12) | Dihexagonal Bipyramids (24) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | Dihexagonal Prisms (12) | Basal Pinacoid (2) | Beryl $Be_3Al_2(SiO_3)_6$ |
| **7. Dihexagonal Pyramidal** (*Holohedrism with Hemimorphism*) | – | 3 | 3 | 1 (*Polar*) | – | – | – | ($u$, $l$) Hexagonal Pyramids First order (6) | ($u$, $l$) Hexagonal Pyramids Second order (6) | ($u$, $l$) Dihexagonal Pyramids (12) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | Dihexagonal Prisms (12) | ($u$, $l$) Basal Pinacoids (1) | Zincite ZnO |
| **8. Ditrigonal Bipyramidal** (*Trigonal Hemihedrism*) | 1 | – | 3 | – | 1 | 3 (*Polar*) | – | (±) Trigonal Bipyramids First order (6) | Hexagonal Bipyramids Second order (12) | (±) Ditrigonal Bipyramids (12) | (±) Trigonal Prisms First order (3) | Hexagonal Prism Second order (6) | (±) Ditrigonal Prisms (6) | Basal Pinacoid (2) | Benitoite $BaTiSi_3O_9$ |
| **9. Ditrigonal Scalenohedral** (*Rhombohedral Hemihedrism*) | – | – | 3 | – | 1 | 3 | 1 | (±) Rhombohedrons First order (6) | Hexagonal Bipyramids Second order (12) | (±) Scalenohedrons (12) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | Dihexagonal Prisms (12) | Basal Pinacoid (2) | Calcite $CaCO_3$ |
| **10. Hexagonal Bipyramidal** (*Pyramidal Hemihedrism*) | 1 | – | – | 1 | – | – | 1 | Hexagonal Bipyramids First order (12) | Hexagonal Bipyramids Second order (12) | (±) Hexagonal Bipyramids Third order (12) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | (±) Hexagonal Prisms Third order (6) | Basal Pinacoid (2) | Apatite $Ca_5Cl(PO_4)_3$ |
| **11. Hexagonal Trapezohedral** (*Trapezohedral Hemihedrism*) | – | – | – | 1 | | 3+3 | – | Hexagonal Bipyramids First order (12) | Hexagonal Bipyramids Second order (12) | ($r$, $l$) Hexagonal Trapezohedrons (12) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | Dihexagonal Prisms (12) | Basal Pinacoid (2) | Barium Stibiotartrate and Potassium Nitrate $Ba(SbO)_2C_4H_4O_6)_2+KNO_3$ |

| Class | Symmetry: Planes: Horizontal: Axial | Symmetry: Planes: Vertical: Axial | Symmetry: Planes: Vertical: Intermediate | Symmetry: Axes: Vertical: ⬢ | Symmetry: Axes: Vertical: ▲ | Symmetry: Axes: Horizontal: ⬬ | Symmetry: Center | Forms: $a:\infty a:a:mc$ {$10\bar{1}1$} | Forms: $2a:2a:a:mc$ {$hh2\bar{h}l$} | Forms: $na:pa:a:mc$ {$hik\bar{l}$} | Forms: $a:\infty a:a:\infty c$ {$10\bar{1}0$} | Forms: $2a:2a:a:\infty c$ {$11\bar{2}0$} | Forms: $na:pa:a:\infty c$ {$hik\dot{o}$} | Forms: $\infty a:\infty a:\infty a:c$ {0001} | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **12. Ditrigonal Pyramidal** [*Trigonal Hemihedrism with Hemimorphism*] | – | – | 3 | – | 1 (*Polar*) | – | – | $(\pm u, \pm l)$ Trigonal Pyramids First order (3) | $(u, l)$ Hexagonal Pyramids Second order (6) | $(\pm u, \pm l)$ Ditrigonal Pyramids (6) | $(\pm)$ Trigonal Prisms First order (3) | Hexagonal Prism Second order (6) | $(\pm)$ Ditrigonal Prisms (6) | $(u, l)$ Basal Pinacoids (1) | Tourmaline $H_{20}B_2Si_4O_{21}$ |
| **13. Hexagonal Pyramidal** [*Pyramidal Hemihedrism with Hemimorphism*] | – | – | – | 1 (*Polar*) | – | – | – | $(u, l)$ Hexagonal Pyramids First order (6) | $(u, l)$ Hexagonal Pyramids Second order (6) | $(\pm u, \pm l)$ Hexagonal Pyramids Third order (6) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | $(\pm)$ Hexagonal Prisms Third order (6) | $(u, l)$ Basal Pinacoids (1) | Strontium Antimonyl-tartrate $Sr(SbO)_2(C_4H_4O_6)_2$ |
| **14. Trigonal Bipyramidal** [*Trigonal Tetartohedrism*] | 1 | – | – | – | 1 | – | – | $(\pm)$ Trigonal Bipyramids First order (6) | $(\pm)$ Trigonal Bipyramids Second order (6) | $(\pm r, \pm l)$ Trigonal Bipyramids Third order (6) | $(\pm)$ Trigonal Prisms First order (3) | $(\pm)$ Trigonal Prisms Second order (3) | $(\pm r, \pm l)$ Trigonal Prisms Third order (3) | Basal Pinacoid (2) | —— |
| **15. Trigonal Trapezohedral** [*Trapezohedral Tetartohedrism*] | – | – | – | – | 1 | 3 (*Polar*) | – | $(\pm)$ Rhombohedrons First order (6) | $(\pm)$ Trigonal Bipyramids Second order (6) | $(\pm r, \pm l)$ Trigonal Trapezohedrons (6) | Hexagonal Prism First order (6) | $(\pm)$ Trigonal Prisms Second order (3) | $(\pm)$ Ditrigonal Prisms (6) | Basal Pinacoid (2) | Quartz $SiO_2$ |
| **16. Trigonal Rhombohedral** [*Rhombohedral Tetartohedrism*] | – | – | – | – | 1 | – | 1 | $(\pm)$ Rhombohedrons First order (6) | $(\pm)$ Rhombohedrons Second order (6) | $(\pm r, \pm l)$ Rhombohedrons Third order (6) | Hexagonal Prism First order (6) | Hexagonal Prism Second order (6) | $(\pm)$ Hexagonal Prisms Third order (6) | Basal Pinacoid (2) | Dioptase $H_2CuSiO_4$ |
| **17. Trigonal Pyramidal** (*Ogdohedrism*) | – | – | – | – | 1 (*Polar*) | – | – | $(\pm u, \pm l)$ Trigonal Pyramids First order (3) | $(\pm u, \pm l)$ Trigonal Pyramids Second order (3) | $\begin{bmatrix}\pm r, u\\ \pm r, l\\ \pm l, u\\ \pm l, l\end{bmatrix}$ Trigonal Pyramids Third order (3) | $(\pm)$ Trigonal Prisms First order (3) | $(\pm)$ Trigonal Prisms Second order (3) | $(\pm r, \pm l)$ Trigonal Prisms Third order (3) | $(u, l)$ Basal Pinacoids (1) | Sodium Periodate $NaIO_4+3H_2O$ |

| Class | Symmetry: Planes: Horizontal: Axial | Symmetry: Planes: Vertical: Axial | Symmetry: Planes: Vertical: Intermédiate | Symmetry: Axes: ● | Symmetry: Axes: ⬢ | Symmetry: Center | Forms: $a:a:mc$ {*hhl*} | Forms: $a:\infty a:mc$ {*hol*} | Forms: $a:na:mc$ {*hkl*} | Forms: $a:a:\infty c$ {110} | Forms: $a:\infty a:\infty c$ {100} | Forms: $a:na:\infty c$ {*hko*} | Forms: $\infty a:\infty a:c$ {001} | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. **Ditetragonal Bipyramidal** (*Holohedrism*) | 1 | 2 | 2 | 1 | 2+2 | 1 | Tetragonal Bipyramids First order (8) | Tetragonal Bipyramids Second order (8) | Ditetragonal Bipyramids (16) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | Ditetragonal Prisms (8) | Basal Pinacoid (2) | Cassiterite $SnO_2$ |
| 19. **Ditetragonal Pyramidal** [*Holohedrism with Hemimorphism*] | – | 2 | 2 | 1 (*Polar*) | – | – | (*u*, *l*) Tetragonal Pyramids First order (4) | (*u*, *l*) Tetragonal Pyramids Second order (4) | (*u*, *l*) Ditetragonal Pyramids (8) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | Ditetragonal Prisms (8) | (*u*, *l*) Basal Pinacoids (1) | Silver Fluoride $AgF+H_2O$ |
| 20. **Tetragonal Scalenohedral** [*Sphenoidal Hemihedrism*] | – | – | 2 | – | 1+2 | – | (±) Tetragonal Bisphenoids First order (4) | Tetragonal Bipyramids Second order (8) | (±) Tetragonal Scalenohedrons (8) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | Ditetragonal Prisms (8) | Basal Pinacoid (2) | Chalcopyrite $CuFeS_2$ |
| 21. **Tetragonal Bipyramidal** [*Pyramidal Hemihedrism*] | 1 | – | – | 1 | – | 1 | Tetragonal Bipyramids First order (8) | Tetragonal Bipyramids Second order (8) | (±) Tetragonal Bipyramids Third order (8) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | (±) Tetragonal Prisms Third order (4) | Basal Pinacoid (2) | Scheelite $CaWO_4$ |
| 22. **Tetragonal Trapezohedral** [*Trapezohedral Hemihedrism*] | – | – | – | 1 | 2+2 | – | Tetragonal Bipyramids First order (8) | Tetragonal Bipyramids Second order (8) | (*r*, *l*) Tetragonal Trapezohedrons (8) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | Ditetragonal Prisms (8) | Basal Pinacoid (2) | Nickel Sulphate $NiSO_4+6H_2O$ |
| 23. **Tetragonal Pyramidal** [*Pyramidal Hemihedrism with Hemimorphism*] | – | | | 1 (*Polar*) | | – | (*u*, *l*) Tetragonal Pyramids First order (4) | (*u*, *l*) Tetragonal Pyramids Second order (4) | (±*u*, ±*l*) Tetragonal Pyramids Third order (4) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | (±) Tetragonal Prisms Third order (4) | (*u*, *l*) Basal Pinacoids (1) | Wulfenite $PbMoO_4$ |
| 24. **Tetragonal Bisphenodial** (*Tetartohedrism*) | – | – | – | – | 1 | – | (±) Tetragonal Bisphenoids First order (4) | (±) Tetragonal Bisphenoids Second order (4) | (±*r*, ±*l*) Tetragonal Bisphenoids Third order (4) | Tetragonal Prism First order (4) | Tetragonal Prism Second order (4) | (±) Tetragonal Prisms Third order (4) | Basal Pinacoid (2) | —— |

## 4. Orthorhombic System

| Class | Symmetry | | | Forms | | | | | | | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Planes | Axes | Center | $n\breve{a}:\bar{b}:m\dot{c}$ {*hkl*} | $n\breve{a}:\bar{b}:\infty\dot{c}$ {*hko*} | $\infty\breve{a}:\bar{b}:m\dot{c}$ {*ohl*} | $\breve{a}:\infty\bar{b}:m\dot{c}$ {*hol*} | $\infty\breve{a}:\bar{b}:\infty\dot{c}$ {010} | $\breve{a}:\infty\bar{b}:\infty\dot{c}$ {100} | $\infty\breve{a}:\infty\bar{b}:\dot{c}$ {001} | |
| | Axial | ● | | | | | | | | | |
| 25. **Orthorhombic Bipyramidal** (*Holohedrism*) | 1+1+1 | 1+1+1 | 1 | Bipyramids (8) | Prisms (4) | Brachydomes (4) | Macrodomes (4) | Brachy-pinacoid (2) | Macro-pinacoid (2) | Basal Pinacoid (2) | Barite $BaSO_4$ |
| 26. **Orthorhombic Pyramidal** (*Holohedrism with Hemimorphism*) | 1+1 | 1 (*Polar*) | – | (*u*, *l*) Pyramids (4) | Prisms (4) | (*u*, *l*) Brachydomes (2) | (*u*, *l*) Macrodomes (2) | Brachy-pinacoid (2) | Macro-pinacoid (2) | (*u*, *l*) Basal Pinacoids (1) | Calamine $Zn_2H_2SiO_5$ |
| 27. **Orthorhombic Bisphenoidal** (*Hemihedrism*) | – | 1+1+1 | – | (*r*, *l*) Bisphenoids (4) | Prisms (4) | Brachydomes (4) | Macrodomes (4) | Brachy-pinacoid (2) | Macro-pinacoid (2) | Basal Pinacoid (2) | Epsomite $MgSO_4+7H_2O$ |

## 5. Monoclinic System.

| Class | Symmetry | | | Forms | | | | | | | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plane | ● Axis | Center | $na:\bar{b}:mc$ {hkl} | $na:\bar{b}:\infty c$ {hko} | $\infty a:\bar{b}:mc$ {ohl} | $a:\infty\bar{b}:\infty c$ {hol} | $\infty a:\bar{b}:\infty c$ {010} | $a:\infty\bar{b}:\infty c$ {100} | $\infty a;\infty\bar{b}:c$ {001} | |
| 28. **Monoclinic Prismatic** (*Holohedrism*) | 1 | 1 | 1 | (±) Hemi-pyramids (4) | Prisms (4) | Clinodomes (4) | (±) Hemi-orthodomes (2) | Clinopinacoid (2) | Orthopinacoid (2) | Basal Pinacoid (2) | Gypsum $CaSO_4+2H_2O$ |
| 29. **Monoclinic Domatic** (*Hemihedrism*) | 1 | – | – | (±*u*, ±*l*) Tetra-pyramids (2) | (*f*, *r*) Hemi-prisms (2) | (*u*, *l*) Hemi-clinodomes (2) | (±*u*, ±*l*) Tetra-orthodomes (1) | Clinopinacoid (2) | (*f*, *r*) Orthopinacoids (1) | (*u*, *l*) Basal Pinacoids (1) | Tetrathionate of Potassium $K_2S_4O_6$ |
| 30. **Monoclinic Sphenoidal** (*Hemimorphism*) | – | 1 (*Polar*) | – | (±*r*, ±*l*) Tetra-pyramids (*Sphenoids*) (2) | (*r*, *l*) Hemi-prisms (2) | (*r*, *l*) Hemi-clinodomes (2) | (±) Hemi-orthodomes (2) | (*r*, *l*) Clinopinacoids (1) | Orthopinacoid (2) | Basal Pinacoid (2) | Tartaric Acid $C_4H_6O_6$ |

## 6. Triclinic System

| Class | Symmetry | | | Forms | | | | | | | Representative |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plane | Axis | Center | $n\breve{a}:\bar{b}:m\dot{c}$ {*hkl*} | $n\breve{a}:\bar{b}:\infty\dot{c}$ {*hko*} | $\infty\breve{a}:\bar{b}:m\dot{c}$ {*ohl*} | $\breve{a}:\infty\bar{b}:m\dot{c}$ {*hol*} | $\infty\breve{a}:\bar{b}:\infty\dot{c}$ {010} | $\breve{a}:\infty\bar{b}:\infty\dot{c}$ {100} | $\infty\breve{a}:\infty\bar{b}:\dot{c}$ {001} | |
| 31. **Triclinic Pinacoidal** (*Holohedrism*) | – | – | 1 | $\left(\frac{u}{l}r, \frac{u}{l}l\right)$ Tetra-pyramids (2) | $(r, l)$ Hemi-prisms (2) | $(r, l)$ Hemi-brachydomes (2) | $(u, l)$ Hemi-macrodomes (2) | Brachy-pinacoid (2) | Macro-pinacoid (2) | Basal Pinacoid (2) | Albite $NaAlSi_3O_8$ |
| 32. **Triclinic Asymmetric** (*Hemihedrism*) | – | – | – | $\left\{\begin{matrix}\frac{u}{l}r, f\\ \frac{u}{l}l, f\\ \frac{u}{l}r, r\\ \frac{u}{l}l, r\end{matrix}\right\}$ Ogdo-pyramids (1) | $\left(\frac{r}{l}f, \frac{r}{l}r\right)$ Tetra-prisms (1) | $\left(\frac{u}{l}r, \frac{u}{l}l\right)$ Tetra-brachydomes (1) | $\left(\frac{u}{l}f, \frac{u}{l}r\right)$ Tetra-macrodomes (1) | $(l, r)$ Brachy-pinacoids (1) | $(f, r)$ Macro-pinacoids (1) | $(u, l)$ Basal Pinacoids (1) | Strontium bitartrate $Sr(C_4H_4O_6H)_2+4H_2O$ |

# Tables for the Determination of the 150 Minerals Described in This Text by Means of Their Physical Properties, Occurrences, and Associates

(Pages 380 to 547).

## A. MINERALS WITH METALLIC LUSTER

| Color of mineral | Streak | Hardness | Page |
|---|---|---|---|
| 1. **Dark gray or black** | White, gray, green, red, brown, or yellow | 1 to 3 | **382** |
| | | 3 to 6 | **384** |
| | | Over 6 | **390** |
| | Black | 1 to 3 | **394** |
| | | Over 3 | **398** |
| 2. **Metallic white or light metallic gray** | Metallic white or steel gray | 1 to 6 | **402** |
| | Black | 1 to 3 | **402** |
| | | Over 3 | **404** |
| 3. **Yellow** | Brown or yellow | 1 to 6 | **406** |
| | Black | Over 3 | **406** |
| 4. **Brass, bronze, or copper red** | Gray, red, or yellow | 1 to 3 | **408** |
| | Black | Over 3 | **408** |
| 5. **Red, brown, or blue** | White, gray, green, red, brown, or yellow | 1 to 3 | **412** |
| | | 3 to 6 | **414** |
| | | Over 6 | **418** |
| | Black | 1 to 6 | **420** |

## B. MINERALS WITH NON-METALLIC LUSTER

| Color of mineral | Streak | Hardness | Page |
|---|---|---|---|
| 1. Dark gray or black | Green, red, brown, yellow, or black | 1 to 6 | 422 |
| | | Over 6 | 426 |
| | Uncolored, white, or light gray. | 1 to 3 | 428 |
| | | 3 to 6 | 430 |
| | | Over 6 | 432 |
| 2. Pink, red, or red violet | Red, brown, or yellow | 1 to 3 | 438 |
| | | Over 3 | 440 |
| | Uncolored, white, or light gray. | 1 to 3 | 444 |
| | | 3 to 6 | 446 |
| | | Over 6 | 452 |
| 3. Green, blue, or blue violet | Blue, green, brown, or yellow | 1 to 6 | 460 |
| | Uncolored, white, or light gray. | 1 to 3 | 464 |
| | | 3 to 6 | 468 |
| | | Over 6 | 478 |
| 4. Yellow or brown | Red, brown, or yellow | 1 to 3 | 486 |
| | | Over 3 | 488 |
| | Uncolored, white, or light gray. | 1 to 3 | 492 |
| | | 3 to 6 | 498 |
| | | Over 6 | 508 |
| 5. Colorless, white, or light gray | Uncolored, white, or light gray. | 1 to 3 | 516 |
| | | 3 to 6 | 524 |
| | | Over 6 | 538 |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CHLORITE** (Procblorite, clinocblorite) $H_8Mg_5Al_2Si_3O_{18}$? **297** | Monoclinic **C**—Tabular, six-sided, often bent and twisted **M**—Foliated, scaly, granular, earthy | Dull Submetallic Translucent to opaque | Black Greenish black |
| **HEMATITE,** variety *Specular iron ore* $Fe_2O_3$ **230** | Hexagonal **C**—Thin tabular, often in parallel position **M**—Scaly, micaceous, platy, foliated | Metallic Splendent Opaque, to translucent | Iron black Dark steel gray |
| **BIOTITE** (Black mica) $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ **294** | Monoclinic **C**—Tabular, with hexagonal or rhombohedral habit **M**—Plates, disseminated scales | Submetallic Pearly Opaque to transparent | Black Brownish black Greenish black |
| **Pyrargyrite** $Ag_3SbS_3$ **217** | Hexagonal **C**—Small, complex, hemimorphic, rare **M**—Compact, disseminated, bands, crusts | Metallic Adamantine Opaque to transparent | Dark lead gray |
| **SILVER** Ag **199** | Cubic **C**—Small, often distorted **M**—Grains, scales, plates, twisted hair- or wire-like forms | Metallic Opaque | Dark gray to black after exposure, otherwise silver white |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2.5 | Pale green | C—Basal, perfect; when foliated, conspicuous<br>F—Scaly, earthy<br>Tough to brittle | 2.6<br>3. | Laminæ are flexible but inelastic, with slightly soapy feel. Common in schists and serpentine. With magnetite, garnet, diopside, magnesite. Often as a scaly or dusty coating on other minerals. Pseudomorphous after garnet. |
| 2.<br>3. | Cherry red<br>Reddish brown | C—None, but distinct parting<br>F—Uneven<br>Brittle to elastic | 4.9<br>5.3 | Bright, shiny scales, often loosely compact; foliated or micaceous masses. In metamorphic rocks or as sublimation product around volcanoes. |
| 2.5<br>3. | White<br>Grayish | C—Basal, perfect, conspicuous<br>Tough, laminæ of fresh biotite very elastic | 2.7<br>3.2 | Easily recognized by structure, highly perfect cleavage, and elasticity. Important constituent of many igneous and metamorphic rocks—granite, syenite, gneiss. |
| 2.5<br>3. | Cherry red<br>Purplish red | C—Imperfect<br>F—Conchoidal<br>Brittle | 5.8 | Frequently as gray or dark red bands, known as *dark ruby silver ore*. With proustite; in veins with other silver minerals and galena. |
| 2.5<br>3. | Silver white<br>Light lead gray | C—None<br>F—Hackly<br>Malleable, ductile | 10.<br>12. | Color and streak darken on exposure. With silver, lead, arsenic, cobalt, and nickel minerals—argentite, pyrargyrite, proustite, galena, smaltite; also fluorite, calcite, barite. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **TETRAHEDRITE**<br>$Cu_8Sb_2S_7$<br>**218** | Cubic<br>**C**—Tetrahedral, often highly modified<br>**M**—Granular, compact | Metallic<br>Opaque | Dark steel gray<br>Iron black |
| **Uraninite** (Pitchblende)<br>$UO_3$, $UO_2$, PbO, etc.<br>**262** | Cubic<br>**C**—Octahedral, rare<br>**M**—Botryoidal, columnar, curved lamellar; granular, compact; apparently amorphous. | Pitch-like<br>Submetallic<br>Dull<br>Opaque | Pitch black<br>Brownish black<br>Greenish black |
| **SIDERITE**<br>$FeCO_3$<br>**248** | Hexagonal<br>**C**—Rhombohedral, curved or saddle-shaped, common<br>**M**—Cleavable, granular, compact, botryoidal, rarely fibrous | Metalloidal<br>Dull<br>Opaque to translucent | Brownish black<br>Black |
| **SPHALERITE** (Black Jack)<br>ZnS<br>**205** | Cubic<br>**C**—Tetrahedral, common, often very complex<br>**M**—Compact, cleavable, fine or coarse granular | Submetallic<br>Resinous<br>Opaque to translucent | Black<br>Yellowish black<br>Brownish black |
| **MANGANITE**<br>MnO.OH<br>**234** | Orthorhombic<br>**C**—Columnar, prismatic, vertically striated; often in groups or bundles<br>**M**—Columnar, granular, stalactitic | Metallic<br>Submetallic<br>Opaque | Iron black<br>Dark steel gray |
| **TITANITE** (Sphene)<br>$CaTiSiO_5$<br>**323** | Monoclinic<br>**C**—Wedge- or envelope-shaped when disseminated, tabular or prismatic when attached<br>**M**—Compact, lamellar | Submetallic<br>Vitreous<br>Opaque to translucent | Black<br>Brownish black |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.**<br>**4.** | Reddish brown | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 4.3<br>5.4 | Crystals have characteristic tetrahedral habit. Sometimes coated with chalcopyrite. With sphalerite, galena, bournonite, chalcopyrite, siderite. |
| **3.**<br>**5.5** | Dark brown<br>Olive green | **F**—Conchoidal, uneven<br>Brittle | 4.8<br>9.7 | Pitch-like appearance and fracture important. Fresh material is hard and heavy. With ores of lead, silver, and bismuth; also orthite. |
| **3.5**<br>**4.** | Yellowish brown | **C**—Rhombohedral, perfect, conspicuous<br>**F**—Conchoidal<br>Brittle | 3.7<br>3.9 | Distinguished from sphalerite by curved crystals and rhombohedral cleavage. In ore deposits; beds and concretions in limestones and shales. With pyrite, chalcopyrite, galena, tetrahedrite, cryolite. |
| **3.5**<br>**4.** | Dark brown<br>Yellowish brown<br>Grayish | **C**—Dodecahedral, perfect, usually conspicuous<br>**F**—Conchoidal<br>Brittle | 3.9<br>4.2 | Color and streak vary with impurities. Extensively in limestone. With galena, chalcopyrite, pyrite, barite, fluorite, siderite, rhodochrosite. |
| **3.5**<br>**4.** | Reddish brown<br>Blackish brown | **C**—Brachypinacoidal, perfect<br>**F**—Uneven<br>Brittle | 4.2<br>4.4 | Alters easily to pyrolusite, hence, surface may give black streak. With other manganiferous minerals; also barite, calcite, siderite. |
| **5.**<br>**5.5** | White<br>Gray | **C**—Prismatic<br>**F**—Conchoidal<br>Brittle | 3.4<br>3.6 | Generally in crystals. With feldspars, pyroxenes, amphiboles, chlorite, scapolite, zircon, apatite. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **LIMONITE**<br>$Fe_2O_3.H_2O$<br>**235** | **C**—Always pseudomorphs, commonly after pyrite, marcasite, siderite<br>**M**—Compact, stalactitic, botryoidal, reniform; often with internal, radial fibrous structure | Metallic<br>Dull<br>Opaque | Black<br>Brownish black |
| **Hausmannite**<br>$Mn_2MnO_4$<br>**253** | Tetragonal<br>**C**—Acute pyramidal, cyclic twins not uncommon<br>**M**—Granular, compact | Metallic<br>Greasy<br>Opaque | Black<br>Brownish black |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long fibrous, bladed, stalky; often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Submetallic<br>Resinous<br>Translucent to opaque | Brownish black<br>Black |
| **WOLFRAMITE**<br>$(Fe,Mn)WO_4$<br>**261** | Monoclinic<br>**C**—Thick tabular, short columnar, often large<br>**M**—Bladed, curved lamellar, granular | Submetallic<br>Metallic<br>Opaque | Dark gray<br>Brownish black<br>Iron black |
| **Ferberite**<br>$FeWO_4$<br>**261** | Monoclinic<br>**C**—Wedge shaped, short prismatic, tabular<br>**M**—Fan shaped aggregates, bladed, granular, compact | Submetallic<br>Splendent<br>Opaque | Iron black<br>Brownish black |

Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>5.5 | Yellowish brown | F—Conchoidal, splintery<br>Brittle | 3.6<br>4. | Often with black varnish-like surface, passing into the soft, yellow earthy or ocherous variety. With pyrite, hematite, magnetite, siderite. Pseudomorphs after pyrite very common. |
| 5.<br>5.5 | Chestnut brown | C—Basal, perfect<br>F—Uneven<br>Brittle | 4.7<br>4.8 | Steep, horizontally striated, octahedral-like bipyramids and complex twins. With manganese minerals—pyrolusite, psilomelane, braunite; magnetite, barite, hematite. |
| 5.<br>5.5 | Yellowish brown<br>Greenish gray | C—Clinopinacoidal, perfect, conspicuous.<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and specific gravity important. Compare wolframite. In quartz veins, with fluorite, pyrite, scheelite, galena, tetrahedrite. |
| 5.<br>5.5 | Dark red brown | C—Clinopinacoidal, perfect, conspicuous.<br>F—Uneven<br>Brittle | 7.1<br>7.5 | Distinguished from huebnerite by streak. Powder may be slightly magnetic. With cassiterite, quartz, mica, fluorite, apatite, scheelite, molybdenite, huebnerite, chalcopyrite. |
| 5.<br>5.5 | Dark brown | C—Clinopinacoidal, perfect.<br>F—Uneven<br>Brittle | 7.5 | In granites and pegmatites. With quartz, chalcopyrite, galena, scheelite. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **HORNBLENDE** (Amphibole) Silicate of Ca, Mg, Fe, Al, etc. **312** | Monoclinic **C**—Long prismatic, prism angle 124°; often with rhombohedral-like terminations **M**—Bladed, fibrous, granular, compact | Submetallic Vitreous Opaque to translucent | Pitch black Greenish black Brownish black |
| **AUGITE** (Pyroxene) Silicate of Ca, Mg, Fe, Al, etc. **307** | Monoclinic **C**—Short prismatic, thick columnar, prism angle 87° **M**—Compact, granular, disseminated | Submetallic Vitreous Opaque to translucent | Pitch black Greenish black Brownish black |
| **Psilomelane** $MnO_2$, BaO, $H_2O$, etc. **253** | Amorphous ? **M**—Botryoidal, reniform, stalactitic; smooth surfaces | Metallic Dull Opaque | Iron black Bluish black Dark gray |
| **Ilmenite** (Menaccanite) $FeTiO_3$ **303** | Hexagonal **C**—Thick tabular, rhombohedral **M**—Thin plates, granular, compact; disseminated grains; pebbles or sand | Metallic Submetallic Opaque | Iron black Brownish black |
| **CHROMITE** $(Fe,Cr)\ [(Cr,Fe)O_2]_2$ **270** | Cubic **C**—Octahedral, rare **M**—Compact, granular, disseminated | Submetallic Pitchy Opaque | Iron black Brownish black |
| **Orthite** (Allanite) $Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$ **287** | Monoclinic **C**—Tabular, rare **M**—Compact, granular, bladed, disseminated grains | Submetallic Greasy Opaque to translucent | Black Pitch black Brownish black |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.**<br>**6.** | Gray<br>Grayish green<br>Grayish brown<br>Yellow | C—Prismatic, perfect, conspicuous—124°<br>Brittle | 2.9<br>3.3 | Simple, pseudohexagonal crystals and cleavages at 56° and 124° important. Very common and in nearly all types of rocks. With calcite, feldspars, quartz, pyroxenes, chlorite. |
| **5.**<br>**6.** | Grayish green<br>Gray | C—Prismatic, perfect, conspicuous—87°<br>Brittle | 3.2<br>3.6 | Crystals usually eight-sided, more rarely four-sided. Pseudotetragonal, with prism angles of 87° and 93°. Cleavage less distinct than on hornblende. Common in basic eruptive rocks and crystalline limestones. |
| **5.**<br>**6.** | Dark brown<br>Blackish brown | F—Conchoidal, uneven<br>Brittle | 3.7<br>4.7 | Often with fine sooty coating of pyrolusite. With other manganese minerals; limonite, barite. |
| **5.**<br>**6.** | Dark brown<br>Reddish brown | C—None, partings may be noted<br>F—Conchoidal<br>Brittle | 4.3<br>5.5 | Often slightly magnetic. With hematite, magnetite, apatite, serpentine, titanite, rutile. Common in black sands. |
| **5.5** | Dark brown<br>Grayish brown | C—Octahedral, indistinct<br>F—Uneven, conchoidal<br>Brittle | 4.3<br>4.6 | May be slightly magnetic. Pitch-like appearance. With serpentine, talc, chrome garnet; also in black sands and platinum placers. |
| **5.5**<br>**6.** | Grayish<br>Brownish gray<br>Pale brown | C—Pinacoidal, indistinct<br>F—Uneven, conchoidal<br>Brittle | 3.<br>4. | Often coated with yellowish or brownish alteration product. Disseminated in the more acid igneous rocks; also in limestones. With magnetite, epidote, quartz, feldspars. |

Streak—White, gray, green, red, brown, or yellow

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **HEMATITE,** varieties<br>*Specular iron ore*<br>$Fe_2O_3$ *Compact*<br>*Martite*<br>*Argillaceous*<br>**230** | Hexagonal<br>**C**—Pyramidal, tabular, rhombohedral<br>**M**—Compact, granular, micaceous, columnar, radiated reniform or botryoidal | Metallic<br>Dull<br>Opaque | Iron black<br>Reddish black<br>Dark steel gray |
| **FRANKLINITE**<br>$(Fe,Mn,Zn)(FeO_2)_2$<br>**270** | Cubic<br>**C**—Octahedrons, alone or with dodecahedron; often with rounded edges<br>**M**—Compact, granular, rounded grains | Metallic<br>Dull<br>Opaque | Iron black |

Streak—White, gray, green, red, brown, or yellow

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **HEMATITE,** varieties<br>*Specular iron ore*<br>$Fe_2O_3$ *Compact*<br>*Martite*<br>*Argillaceous*<br>**230** | Hexagonal<br>**C**—Pyramidal, tabular, rhombohedral<br>**M**—Compact, granular, micaceous, columnar, radiated reniform or botryoidal | Metallic<br>Dull<br>Opaque | Iron black<br>Reddish black<br>Dark steel gray |
| **FRANKLINITE**<br>$(Fe,Mn,Zn)(FeO_2)_2$<br>**270** | Cubic<br>**C**—Octahedrons, alone or with dodecahedron; often with rounded edges<br>**M**—Compact, granular, rounded grains | Metallic<br>Dull<br>Opaque | Iron black |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.5<br>6. | Cherry red<br>Reddish brown | C—None, parting sometimes noted<br>F—Uneven<br>Brittle | 4.9<br>5.3 | *Specular iron ore*, crystals or sparkling scales and grains, often with iridescent tarnish; *compact hematite*, fibrous, columnar, reniform; *martite*, octahedral crystals, pseudomorphous after magnetite; *argillaceous hematite*, impure from sand, clay, jasper. |
| 5.5<br>6. | Reddish brown<br>Dark brown | C—Octahedral, indistinct<br>F—Conchoidal<br>Brittle | 5.<br>5.2 | Powder frequently slightly magnetic. Distinguished by associates—willemite (yellow to green), zincite (red), rhodonite (flesh red), calcite. |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>6.5 | Cherry red<br>Reddish brown | C—None, parting sometimes noted<br>F—Uneven<br>Brittle | 4.9<br>5.3 | *Specular iron ore*, crystals or sparkling scales and grains, often with iridescent tarnish; *compact hematite*, fibrous, columnar, reniform; *martite*, octahedral crystals, pseudomorphous after magnetite; *argillaceous hematite*, impure from sand, clay, jasper. |
| 6.<br>6.5 | Reddish brown<br>Dark brown | C—Octahedral, indistinct<br>F—Conchoidal<br>Brittle | 5.<br>5.2 | Powder frequently slightly magnetic. Distinguished by associates—willemite (yellow to green), zincite (red), rhodonite (flesh red), calcite. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **COLUMBITE** (Tantalite)<br>$(Fe,Mn)[(Nb,Ta)O_3]_2$<br>**273** | Orthorhombic<br>**C**—Short prismatic, tabular<br>**M**—Compact, disseminated | Submetallic<br>Greasy<br>Dull<br>Opaque | Iron black<br>Brownish black |
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Metallic<br>Adamantine<br>Opaque to translucent | Iron black<br>Brownish black<br>Reddish black |
| **CASSITERITE,** varieties<br>*Ordinary*<br>*Stream tin*<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic, knee-shaped twins, common<br>**M**—Compact, reniform, botryoidal, rounded pebbles | Submetallic<br>Dull<br>Translucent to opaque | Black<br>Brownish black |
| **GARNET,** varieties<br>*Andradite*<br>$R_3''R_2'''(SiO_4)_3$ *Almandite*<br>$R'' = Ca,Fe,Mg$<br>$R''' = Al,Fe$<br>**290** | Cubic<br>**C**—Dodecahedrons, tetragonal trisoctahedrons, alone or in combination, common<br>**M**—Granular, compact, lamellar, disseminated, sand | Submetallic<br>Translucent to opaque | Velvet black<br>Brownish black |
| **TOURMALINE**<br>$M_9'Al_3(B.OH)_2Si_4O_{19}$<br>$M' = Na,K,Li,Mg,Fe$<br>**284** | Hexagonal<br>**C**—Prismatic, vertically striated, terminated with broken or rhombohedral-like surfaces<br>**M**—Compact, divergent columnar, disseminated | Submetallic<br>Pitchy<br>Opaque | Pitch black<br>Brownish black<br>Bluish black |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **6.**<br>**6.5** | Reddish brown<br>Blackish brown | C—Pinacoidal, not conspicuous<br>F—Conchoidal, uneven<br>Brittle | 5.4<br>6.4 | Fracture surface sometimes iridescent. With beryl, tourmaline, spodumene, cryolite. Tantalum predominates in *tantalite*, and specific gravity may be as high as 9. |
| **6.**<br>**7.** | Pale yellowish brown<br>Gray | C—Prismatic, pyramidal, not conspicuous<br>F—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Sometimes in fine hairlike inclusions. Widely distributed. With quartz, feldspar, hematite, ilmenite, chlorite, apatite. |
| **6.**<br>**7.** | Pale brown<br>Pale yellow<br>White | C—Prismatic, imperfect<br>F—Uneven<br>Brittle | 6.8<br>7. | Distinguished by high specific gravity and hardness. In veins cutting granite, gneiss; also in alluvial deposits, as *stream tin*. With quartz, wolframite, scheelite, arsenopyrite, molybdenite, tourmaline, fluorite, apatite. |
| **6.5**<br>**7.5** | White | C—Dodecahedral, indistinct<br>F—Conchoidal, uneven<br>Brittle | 3.8<br>4.2 | *Andradite*, commonly with magnetite, epidote, feldspars, nephelite, leucite; *almandite*, with mica, staurolite, andalusite, cyanite, tourmaline. |
| **7.**<br>**7.5** | White<br>Gray | C—None<br>F—Conchoidal, uneven<br>Brittle | 2.9<br>3.2 | Spherical triangular cross-section and hemimorphic development important. In pegmatites; metamorphic rocks; alluvial deposits. With quartz, feldspar, cassiterite, beryl, topaz, fluorite. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CORUNDUM,** variety *Emery* $Al_2O_3$ with $Fe_3O_4$, $Fe_2O_3$, $SiO_2$ | Hexagonal **M**—Fine to coarse granular | Metallic Dull Opaque | Dark gray Black |
| **228** | | | |
| **SPINEL,** varieties *Pleonaste* *Hercynite* *Gahnite* *Picotite* *Dysluite* $R_2''(R'''O_2)_2$ R″ = Mg, Fe, Zn, Mn R‴ = Al, Fe | Cubic **C**—Octahedral, well developed, common **M**—Compact, granular, disseminated grains; sand | Submetallic Dull Nearly opaque | Black Brownish black Greenish black |
| **267** | | | |

**Streak—Black**

| | | | |
|---|---|---|---|
| **Molybdenite** $MoS_2$ | Hexagonal **C**—Tabular, rare **M**—Disseminated grains, scales, foliated | Metallic Opaque | Bluish lead gray |
| **205** | | | |
| **GRAPHITE** (Plumbago, black lead) C | Hexagonal **C**—Tabular, rare **M**—Foliated, scaly, granular, earthy | Metallic Dull Opaque | Dark steel gray Iron black |
| **192** | | | |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 7.<br>9. | Yellowish brown<br>Blackish brown | C—Indistinct<br>F—Uneven<br>Brittle to tough | 3.7<br>4.3 | Corundum mixed with magnetite, hematite, quartz. Resembles iron ore, powder may be magnetic. Properties vary with composition. With mica, amphiboles, chlorite, spinel; in crystalline limestones, schists, peridotite. |
| 7.5<br>8. | Grayish<br>Grayish green<br>Pale brown<br>White | C—Octahedral, indistinct<br>F—Conchoidal<br>Brittle | 3.6<br>4.4 | Common contact mineral in granular limestones; in igneous rocks, especially the basic olivine-bearing types; rounded grains in placers. With calcite, chondrodite, serpentine, brucite, olivine, corundum, graphite, pyroxenes. |

**Hardness 1 to 3**

| | | | | |
|---|---|---|---|---|
| 1.<br>1.5 | Dark lead gray; greenish on glazed porcelain (graphite, shiny black) | C—Basal, perfect<br>Sectile, lamellæ are flexible | 4.7<br>4.8 | Marks paper. Soft and greasy like graphite, but heavier and lighter colored. In granite with cassiterite, wolframite; also in crystalline limestone. |
| 1.<br>2. | Black, shiny<br>Dark silver gray | C—Basal, perfect<br>Sectile, lamellæ are flexible | 1.9<br>2.3 | Greasy feel; marks paper; darker than molybdenite and not as heavy. In crystalline limestone with garnet, spinel, pyroxenes, amphiboles; also in shale, gneiss, and mica schist. |

**Streak—Black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **PYROLUSITE**<br>$MnO_2$<br>**227** | Orthorhombic ?<br>**C**—Often pseudomorphous after manganite<br>**M**—Columnar, fibrous, acicular, often divergent; dendritic; powdery | Metallic<br>Dull<br>Opaque | Iron black<br>Dark steel gray |
| **STIBNITE**<br>$Sb_2S_3$<br>**204** | Orthorhombic<br>**C**—Prismatic, bent, twisted, common<br>**M**—Fibrous, bladed, columnar, granular | Metallic<br>Opaque | Dark lead gray<br>Black |
| **Argentite** (Silver glance)<br>$Ag_2S$<br>**213** | Cubic<br>**C**—Octahedral, cubical, often distorted<br>**M**—Compact, arborescent; coatings | Metallic<br>Opaque | Dark lead gray<br>Black |
| **GALENA** (Galenite)<br>PbS<br>**212** | Cubic<br>**C**—Cubes alone, or with octahedron, well developed, common<br>**M**—Granular, cleavable aggregates, compact | Metallic<br>Opaque | Dark lead gray |
| **CHALCOCITE**<br>$Cu_2S$<br>**214** | Orthorhombic<br>**C**—Tabular, pseudohexagonal, deeply striated<br>**M**—Granular, compact, disseminated | Metallic<br>Opaque | Dark lead gray, often tarnished dull black, blue, or green |
| **Bournonite** (Cog-wheel ore)<br>$Pb_2Cu_2Sb_2S_6$<br>**217** | Orthorhombic<br>**C**—Thick tabular; cog-wheel twins<br>**M**—Compact, granular | Metallic<br>Opaque | Dark steel gray<br>Iron black |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2.5 | Black<br>Bluish black | C—Indistinct<br>Brittle | 4.7<br>4.8 | Often soils fingers. Darker than stibnite. With psilomelane, manganite, hematite, limonite, barite. |
| 2.<br>2.5 | Dark lead gray<br>Black | C—Brachypinacoidal, perfect, conspicuous, yielding long, shiny faces<br>Slightly sectile | 4.6<br>4.7 | Tarnishes black, sometimes iridescent. In veins with quartz, sphalerite, galena. cinnabar, barite, gold. |
| 2.<br>2.5 | Dark lead gray, shiny | C—Indistinct<br>F—Hackly<br>Perfectly sectile | 7.2<br>7.4 | Cuts and takes impression like lead, hence easily distinguished from other soft, black minerals. With silver, cobalt, nickel oresproustite, pyrargyrite, smaltite, niccolite. |
| 2.5 | Grayish black<br>Dark lead gray | C—Cubic, perfect, very conspicuous<br>Brittle | 7.3<br>7.6 | Characterized by cleavage and high specific gravity. Changes to cerussite or anglesite. With sphalerite, pyrite, chalcopyrite, calcite, fluorite, barite. |
| 2.5<br>3. | Dark gray, shiny<br>Black, shiny | C—Indistinct<br>F—Conchoidal<br>Rather brittle | 5.5<br>5.8 | More brittle than argentite. Often coated with malachite (green), azurite (blue). With chalcopyrite, bornite, tetrahedrite, galena. |
| 2.5<br>3. | Dark gray<br>Black | C—Imperfect<br>F—Uneven<br>Brittle | 5.7<br>5.9 | Easily recognized by cross or cogwheel appearance. With galena, sphalerite, tetrahedrite, siderite, stibnite, chalcocite. |

Streak—Black

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Enargite**<br>$Cu_3AsS_4$<br>**219** | Orthorhombic<br>**C**—Prismatic, small, rare<br>**M**—Compact, granular, columnar | Metallic<br>Submetallic<br>Opaque | Grayish black<br>Iron black |

Streak—Black

| | | | |
|---|---|---|---|
| **TETRAHEDRITE**<br>$Cu_8Sb_2S_7$<br>**218** | Cubic<br>**C**—Tetrahedral, often highly modified<br>**M**—Granular, compact | Metallic<br>Opaque | Dark steel gray<br>Iron black |
| **Arsenic**<br>As<br>**194** | Hexagonal<br>**C**—Rare<br>**M**—Compact, scaly, fine granular, with reniform or botryoidal structure | Metallic<br>Opaque | Dark gray to black on exposure, tin white on fresh fracture |
| **Uraninite** (Pitchblende)<br>$UO_3$, $UO_2$, PbO, etc.<br>**262** | Cubic<br>**C**—Octahedral, rare<br>**M**—Botryoidal, columnar, curved lamellar, granular, compact, apparently amorphous | Pitch-like<br>Submetallic<br>Dull<br>Opaque | Pitch black<br>Brownish black<br>Greenish black |
| **Ferberite**<br>$FeWO_4$<br>**261** | Monoclinic<br>**C**—Wedge shaped, short prismatic, tabular<br>**M**—Fan shaped aggregates, bladed, granular, compact | Submetallic<br>Splendent<br>Opaque | Iron black<br>Brownish black |
| **WOLFRAMITE**<br>(Fe, Mn)$WO_4$<br>**261** | Monoclinic<br>**C**—Thick, tabular, short columnar, often large<br>**M**—Bladed, curved lamellar, granular, compact | Submetallic<br>Metallic<br>Opaque | Dark gray<br>Brownish black<br>Iron black |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.** | Grayish black | C—Prismatic, perfect, often conspicuous<br>F—Uneven<br>Brittle | 4.4 | In artificial light usually resembles sphalerite. In veins with other copper minerals—chalcopyrite, bornite, chalcocite. |

**Hardness over 3**

| | | | | |
|---|---|---|---|---|
| **3.**<br>**4.** | Dark gray<br>Black | C—Indistinct<br>F—Uneven<br>Brittle | 4.3<br>5.4 | Characteristic crystals sometimes coated with chalcopyrite. With sphalerite, galena, bournonite, siderite, malachite. |
| **3.**<br>**4.** | Dark gray<br>Black | C—Basal, not conspicuous<br>F—Uneven, granular<br>Brittle | 5.6<br>5.8 | Often breaks in concentric or onion-like layers. Color and streaks darken on exposure. With silver, cobalt, nickel ores—proustite, smaltite. |
| **3.**<br>**5.5** | Brownish black<br>Grayish black | F—Conchoidal, uneven<br>Brittle | 4.8<br>9.7 | Pitch-like appearance and fracture important. Fresh material is hard and heavy. With ores of lead, silver, bismuth; pyrite, orthite. |
| **5.**<br>**5.5** | Brownish black | C—Clinopinacoidal, perfect<br>F—Uneven<br>Brittle | 7.1<br>7.5 | In granites and pegmatites. With quartz, chalcopyrite, galena, scheelite. |
| **5.**<br>**5.5** | Brownish black<br>Black | C—Clinopinacoidal, perfect, conspicuous<br>F—Uneven<br>Brittle | 7.1<br>7.5 | Structure, cleavage, and specific gravity important. Powder may be slightly magnetic. With cassiterite, quartz, mica, fluorite, apatite, scheelite, molybdenite, huebnerite. |

**Streak—Black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Psilomelane**<br>$MnO_2$, BaO, $H_2O$, etc.<br>**253** | Amorphous?<br>**M**—Botryoidal, reniform, stalactitic; smooth surface | Metallic<br>Dull<br>Opaque | Iron black<br>Bluish black<br>Dark gray |
| **Ilmenite** (Menaccanite)<br>$FeTiO_3$<br>**303** | Hexagonal<br>**C**—Thick tabular, rhombohedral<br>**M**—Thin plates, granular, compact, disseminated grains, pebbles, sand | Metallic<br>Submetallic<br>Opaque | Iron black<br>Brownish black |
| **MAGNETITE**<br>$Fe(FeO_2)_2$<br>**268** | Cubic<br>**C**—Octahedrons, dodecahedrons, common<br>**M**—Compact, granular, lamellar, disseminated, sand | Metallic<br>Submetallic<br>Dull<br>Opaque | Iron black |
| **FRANKLINITE**<br>$(Fe,Mn,Zn)(FeO_2)_2$<br>**270** | Cubic<br>**C**—Octahedrons, alone or with dodecahedron; edges often rounded<br>**M**—Compact, granular, rounded grains | Metallic<br>Dull<br>Opaque | Iron black |
| **COLUMBITE** (Tantalite)<br>$(Fe,Mn)[(Nb,Ta)O_3]_2$<br>**273** | Orthorhombic<br>**C**—Short prismatic, tabular<br>**M**—Compact, disseminated | Submetallic<br>Greasy<br>Dull<br>Opaque | Iron black<br>Brownish black |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.**<br>**6.** | Black<br>Brownish black | **F**—Conchoidal, uneven<br>Brittle | 3.7<br>4.7 | Often with fine, sooty coating of pyrolusite. With other manganese minerals; limonite, barite. |
| **5.**<br>**6.** | Black<br>Brownish black | **C**—None, partings may be noted<br>**F**—Conchoidal<br>Brittle | 4.5<br>5.5 | Sometimes slightly magnetic but not as strongly as magnetite. With hematite, magnetite, apatite, serpentine, titanite, rutile. Common in black sands. |
| **5.5**<br>**6.5** | Black | **C**—Indistinct, octahedral parting<br>**F**—Conchoidal, uneven<br>Brittle | 4.9<br>5.2 | Very strongly magnetic. Crystals usually perfect and with bright surfaces. Independent deposits; disseminated; black sands. With chlorite, hornblende, pyroxene, feldspar, quartz, pyrite, chalcopyrite, epidote. |
| **5.5**<br>**6.5** | Black<br>Brownish black | **C**—Octahedral, indistinct<br>**F**—Conchoidal<br>Brittle | 5.<br>5.2 | Powder frequently slightly magnetic. Distinguished by associates—willemite (yellow or green), zincite (red), rhodonite (flesh red), calcite. |
| **6.**<br>**6.5** | Black<br>Brownish black<br>Grayish black | **C**—Pinacoidal, not conspicuous<br>**F**—Conchoidal, uneven<br>Brittle | 5.4<br>6.4 | Fracture surface sometimes iridescent. With beryl, tourmaline, spodumene, cryolite. Tantalum predominates in *tantalite* and specific gravity may be as high as 9. |

**Streak—Black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CORUNDUM,** variety *Emery* $Al_2O_3$, with $Fe_3O_4$, $Fe_2O_3$, $SiO_2$ | Hexagonal Always massive, fine to coarse granular | Metallic Dull Opaque | Dark gray Black |
| **228** | | | |

A. MINERALS WITH METALLIC LUSTER

**Streak—Metallic white or steel gray**

| | | | |
|---|---|---|---|
| **Bismuth** Bi | Hexagonal **C**—Rare **M**—Reticulated, arborescent, platy | Metallic Opaque | Silver white, with reddish tinge |
| **195** | | | |
| **SILVER** Ag | Cubic **C**—Small, often distorted **M**—Grains, scales, plates, twisted hair- or wire-like forms, lumps | Metallic Opaque | Silver white, tarnishing yellow, brown, or black |
| **199** | | | |
| **PLATINUM** Pt | Cubic **C**—Small, rare **M**—Scales, grains, nuggets | Metallic Opaque | Tin white Steel gray |
| **195** | | | |

**Streak—Black**

| | | | |
|---|---|---|---|
| **Molybdenite** $MoS_2$ | Hexagonal **C**—Tabular, rare **M**—Disseminated grains, scales, foliated | Metallic Opaque | Bluish lead gray |
| **205** | | | |

### Hardness over 3

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 7.<br>9. | Black<br>Brownish black | C—Indistinct<br>F—Uneven<br>Brittle to tough | 3.7<br>4.3 | Corundum mixed with iron ore. May be magnetic. With mica, amphiboles, chlorite, spinel; in crystalline limestone, schist, peridotite. |

## 2. METALLIC WHITE OR LIGHT METALLIC GRAY IN COLOR

### Hardness 1 to 6

| | | | | |
|---|---|---|---|---|
| 2.<br>2.5 | Lead gray, shiny | C—Basal, perfect, usually conspicuous.<br>Sectile | 9.7<br>9.8 | Often shows brassy tarnish colors. With silver, cobalt, nickel, tin ores—smaltite, niccolite, cassiterite; wolframite. |
| 2.5<br>3. | Silver white, shiny<br>Light lead gray, shiny | C—None<br>F—Hackly<br>Malleable, ductile | 10.<br>12. | Color and streak darken on exposure. With silver, lead, arsenic, cobalt, nickel ores—argentite, pyrargyrite, proustite, galena, smaltite; fluorite, calcite, barite. |
| 4.<br>5. | Light steel gray, shiny | C—None<br>F—Hackly<br>Malleable, ductile | 14.<br>19. | Heavier than silver and does not tarnish. May be magnetic if much iron be present. With chromite, magnetite, gold. |

### Hardness 1 to 3

| | | | | |
|---|---|---|---|---|
| 1.<br>1.5 | Dark lead gray, greenish on glazed porcelain (graphite, shiny black) | C—Basal, perfect<br>Sectile, lamellæ flexible | 4.7<br>4.8 | Marks paper. Soft and greasy like graphite but heavier and lighter colored. In granite with cassiterite, wolframite; in crystalline limestone. |

**Streak—Black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **STIBNITE** $Sb_2S_3$ **204** | Orthorhombic **C**—Prismatic, bent, twisted, common **M**—Fibrous, bladed, columnar, granular, compact | Metallic Opaque | Light lead gray |
| **GALENA** (Galenite) PbS **212** | Cubic **C**—Cubes, alone or with octahedron, common, well developed **M**—Granular, cleavable aggregates | Metallic Opaque | Lead gray |

**Streak—Black**

| | | | |
|---|---|---|---|
| **Arsenic** As **194** | Hexagonal **C**—Rare **M**—Compact, scaly, fine grained, reniform, botryoidal | Metallic Opaque | Tin white, on fresh fracture |
| **Cobaltite** CoAsS **210** | Cubic **C**—Cubes, pyritohedrons, small, well developed **M**—Granular, compact | Metallic Opaque | Silver white Steel gray, at times with reddish tinge |
| **Smaltite** $CoAs_2$ **210** | Cubic **C**—Rare **M**—Granular, compact | Metallic Opaque | Tin white Light steel gray |
| **ARSENOPYRITE** FeAsS **211** | Orthorhombic **C**—Prismatic, common **M**—Compact, granular, columnar, radial | Metallic Opaque | Tin white Light steel gray, tarnishes yellow |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 2.<br>2.5 | Dark lead gray<br>Black | C—Brachypinacoidal, perfect, conspicuous, yielding long shiny faces<br>Slightly sectile | 4.6<br>4.7 | Differs from galena in cleavage and specific gravity. Tarnishes black, sometimes iridescent. In veins with quartz, sphalerite, galena, cinnabar, barite, gold. |
| 2.5 | Dark lead gray<br>Grayish black | C—Cubic, perfect, very conspicuous<br>Brittle. | 7.3<br>7.6 | Characterized by cleavage and high specific gravity. Changes to cerussite, pyromorphite, or anglesite. With sphalerite, pyrite, chalcopyrite, calcite, fluorite, barite. |

**Hardness over 3**

| | | | | |
|---|---|---|---|---|
| 3.<br>4. | Lead gray<br>Grayish black | C—Basal, not conspicuous<br>F—Uneven, granular<br>Brittle | 5.6<br>5.8 | Often breaks in concentric or onion-like layers. Color and streak darken on exposure. With silver, cobalt, nickel ores—proustite, smaltite. |
| 5.5 | Dark grayish black | C—Cubic, not conspicuous<br>F—Uneven<br>Brittle | 6.<br>6.4 | May show red tarnish. Often with pink coating of erythrite (cobalt bloom). With native silver, smaltite, niccolite, pyrrhotite, chalcopyrite. |
| 5.5 | Grayish black | C—Indistinct<br>F—Uneven<br>Brittle | 6.4<br>6.6 | May have dull tarnish and pink coating of erythrite. With niccolite, cobaltite, native bismuth and silver, proustite, barite, fluorite, calcite. |
| 5.5<br>6. | Dark grayish black | C—Prismatic, not conspicuous<br>F—Uneven<br>Brittle | 5.9<br>6.2 | Whiter than marcasite. More common than smaltite. With chalcopyrite, pyrite, sphalerite, cassiterite, smaltite, native gold and silver, serpentine. |

**Streak—Black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **MARCASITE** (White iron pyrites) $FeS_2$ **211** | Orthorhombic C—Tabular, often twinned, resembling cock's combs M—Compact, stalactitic, globular, radiated | Metallic Opaque | Steel gray Pale brass yellow, more brassy on exposure |

## A. MINERALS WITH METALLIC LUSTER

**Streak—Brown or yellow**

| | | | |
|---|---|---|---|
| **LIMONITE,** varieties *Yellow ocher* *Bog iron ore* $Fe_2O_3.H_2O$ **235** | M—Earthy, porous, clay-like | Earthy Dull Opaque | Yellow Brownish yellow |
| **GOLD** Au **200** | Cubic C—Small, often distorted M—Grains, scales, nuggets, dust | Metallic Opaque | Golden yellow Brassy yellow Light yellow |

**Streak—Black**

| | | | |
|---|---|---|---|
| **CHALCOPYRITE** $CuFeS_2$ **215** | Tetragonal C—Bisphenoids, resembling tetrahedrons, common M—Compact | Metallic Opaque | Brass yellow Golden yellow |
| **MARCASITE** (White iron pyrites) $FeS_2$ **211** | Orthorhombic C—Tabular, often twinned, resembling cock's combs M—Compact, stalactitic, globular, radiated | Metallic Opaque | Pale brass yellow, more brassy on exposure |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>6.5 | Dark greenish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.6<br>4.8 | Alters to limonite, melanterite. With other sulphides—galena, sphalerite, chalcopyrite, pyrite; calcite, dolomite. |

## 3. YELLOW IN COLOR

**Hardness 1 to 6**

| | | | | |
|---|---|---|---|---|
| 1.<br>4. | Yellowish brown | C—None<br>F—Earthy<br>Brittle | 3.4<br>4. | *Yellow ocher*, earthy, may have greasy feel, when impure gritty; *bog iron ore*, porous. |
| 2.5<br>3. | Golden yellow | C—None<br>F—Hackly<br>Malleable, ductile | 15.6<br>19.3 | Does not tarnish. Characterized by streak, specific gravity, and tenacity Frequently in quartz veins; placers. Commonly with pyrite, and other sulphides. |

**Hardness over 3**

| | | | | |
|---|---|---|---|---|
| 3.5<br>4. | Greenish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.1<br>4.3 | Softer, and deeper yellow than pyrite. Frequently with iridescent tarnish. With pyrite, bornite, galena, sphalerite, tetrahedrite, chalcocite. |
| 6.<br>6.5 | Dark greenish black<br>Brownish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.6<br>4.8 | Distinguished from pyrite by crystallization and lighter color on fresh fracture. Alters more readily than pyrite, forming limonite, melanterite. Occurrence same as pyrite, less abundant. |

Streak—Black

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **PYRITE** (Iron pyrites, fool's gold) $FeS_2$ **208** | Cubic **C**—Cubes, octahedrons, pyritohedrons, common, often striated **M**—Compact, fine granular; botryoidal, stalactitic | Metallic Opaque | Brass yellow Golden yellow with variegated tarnish |

## A. MINERALS WITH METALLIC LUSTER

Streak—Gray, red, or yellow

| | | | |
|---|---|---|---|
| **Bismuth** Bi **195** | Hexagonal **C**—Rare **M**—Reticulated, arborescent, platy | Metallic Opaque | Light copper red |
| **COPPER** Cu **196** | Cubic **C**—Cubes, octahedrons, tetrahexahedrons **M**—Scales, plates, lumps, arborescent aggregates | Metallic Opaque | Copper red, tarnishing readily red, blue, green, black |
| **GOLD** Au **200** | Cubic **C**—Small, distorted, rare **M**—Grains, scales, dust, nuggets | Metallic Opaque | Golden yellow Brassy yellow Light yellow |

Streak—Black

| | | | |
|---|---|---|---|
| **BORNITE** $Cu_xFe_2S_{\frac{x}{2}+3}$ $x = 6, 10, 12$ **216** | Cubic **C**—Rare **M**—Compact, granular | Metallic Opaque | Bronze brown Copper red, on fresh fracture |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>6.5 | Greenish black<br>Brownish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.9<br>5.2 | Harder than chalcopyrite Alters to limonite. Widely distributed in all types of rocks. With other sulphides—galena, sphalerite, chalcopyrite; quartz. |

## 4. BRASS, BRONZE, OR COPPER RED IN COLOR

**Hardness 1 to 3**

| | | | | |
|---|---|---|---|---|
| 2.<br>2.5 | Lead gray, shiny | C—Basal, perfect, usually conspicuous<br>Sectile | 9.7<br>9.8 | Often shows brassy tarnish. Frequently with silver, cobalt, nickel, tin ore—smaltite, niccolite, cassiterite, wolframite. |
| 2.5<br>3. | Copper red, shiny | C—None<br>F—Hackly<br>Ductile, malleable | 8.5<br>9. | Cementing material in conglomerate or filling cavities in trap rocks. With cuprite, malachite, azurite, native silver, melaconite, epidote, datolite, zeolites. |
| 2.5<br>3. | Golden yellow | C—None<br>F—Hackly<br>Malleable, ductile | 15.6<br>19.3 | Does not tarnish. Characterized by streak, specific gravity, and tenacity. Frequently in quartz veins; placers. Commonly with pyrite and other sulphides. |

**Hardness over 3**

| | | | | |
|---|---|---|---|---|
| 3.<br>3.5 | Grayish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.9<br>5.2 | Usually with peacock tarnish colors (purple copper ore). With chalcopyrite, chalcocite, malachite, cassiterite, siderite. |

**Streak—Black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CHALCOPYRITE** $CuFeS_2$ **215** | Tetragonal<br>**C**—Bisphenoids, resembling tetrahedrons, common<br>**M**—Compact, granular | Metallic<br>Opaque | Brass yellow<br>Golden yellow |
| **PYRRHOTITE** FeS **207** | Hexagonal<br>**C**—Tabular, rare<br>**M**—Compact, granular | Metallic<br>Opaque | Bronze yellow<br>Bronze brown |
| **Niccolite** NiAs **208** | Hexagonal<br>**C**—Rare<br>**M**—Compact, disseminated | Metallic<br>Opaque | Light copper red |
| **MARCASITE** (White iron pyrites) $FeS_2$ **211** | Orthorhombic<br>**C**—Tabular, often twinned resembling cock's combs<br>**M**—Compact, stalactitic, globular, radiated | Metallic<br>Opaque | Steel gray<br>Pale brass yellow, more brassy on exposure |
| **PYRITE** (Iron pyrites, fool'sgold) $FeS_2$ **208** | Cubic<br>**C**—Cubes, octahedrons, pyritohedrons, very common, often striated<br>**M**—Compact, fine granular; botryoidal, stalactitic | Metallic<br>Opaque | Brass yellow<br>Golden yellow, with variegated tarnish |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.5**<br>**4.** | Greenish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.1<br>4.3 | Softer, and deeper yellow in color than pyrite. Frequently with iridescent tarnish. With pyrite, bornite, galena, sphalerite, tetrahedrite, chalcocite. |
| **3.5**<br>**4.5** | Dark grayish black | C—Basal, not conspicuous<br>F—Uneven<br>Brittle | 4.5<br>4.6 | Powder frequently attracted by magnet. Subject to dark brown tarnish. In basic igneous rocks. With chalcopyrite, pyrite, galena. |
| **5.5** | Dark brownish black | C—Indistinct<br>F—Uneven<br>Brittle | 7.3<br>7.7 | Often with green coating of annabergite (nickel bloom). With cobalt, nickel, silver minerals—smaltite, proustite, native silver; native bismuth and arsenic; calcite. |
| **6.**<br>**6.5** | Dark greenish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.6<br>4.8 | Distinguished from pyrite by crystallization and lighter color on fresh fracture. Alters more readily than pyrite, forming limonite, melanterite. Occurrence same as for pyrite, but not as abundant. |
| **6.**<br>**6.5** | Greenish black<br>Brownish black | C—Indistinct<br>F—Uneven<br>Brittle | 4.9<br>5.2 | Alters to limonite. Widely distributed in all types of rocks. With other sulphides—galena, sphalerite, chalcopyrite.; quartz. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **LIMONITE,** varieties<br>*Brown ocher*<br>*Bog iron ore*<br>*Brown clay ironstone*<br>$Fe_2O_3.H_2O$<br>**235** | **C**—Unknown<br>**M**—Compact, earthy, porous, pisolitic, oolitic | Dull<br>Earthy<br>Opaque | Yellowish brown<br>Dark brown |
| **HEMATITE,** varieties<br>*Red ocher*<br>*Oolitic*<br>*Fossiliferous*<br>$Fe_2O_3$<br>**230** | Hexagonal<br>**M**—Fine granular, earthy, scaly, oolitic, fossiliferous | Dull<br>Earthy<br>Opaque | Brownish Cherry red |
| **CINNABAR**<br>HgS<br>**215** | Hexagonal<br>**C**—Rhombohedral, thick tabular, small, rare<br>**M**—Fine granular, fibrous, disseminated, earthy coating | Adamantine<br>Dull<br>Transparent to opaque | Scarlet red<br>Brownish red |
| **Proustite**<br>$Ag_3AsS_3$<br>**217** | Hexagonal<br>**C**—Small, complex, rare<br>**M**—Disseminated, crusts, bands | Adamantine<br>Dull<br>Transparent to translucent | Scarlet<br>Vermilion |
| **Pyrargyrite**<br>$Ag_3SbS_3$<br>**217** | Hexagonal<br>**C**—Small, complex, rare<br>**M**—Disseminated, crusts, bands | Adamantine<br>Metallic<br>Transparent to opaque | Dark red |
| **COPPER**<br>Cu<br>**196** | Cubic<br>**C**—Cubes, octahedrons, tetrahexahedrons<br>**M**—Scales, plates, lumps, arborescent aggregates | Metallic<br>Opaque | Copper red, tarnishing readily to red, blue, green, black |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>3. | Yellowish brown | C—None<br>F—Earthy<br>Brittle | 3.4<br>4. | *Brown ocher*, earthy, may soil fingers; *bog iron ore*, porous; *brown clay iron-stone*, massive or concretionary, impure from clay, sand. |
| 1.<br>3. | Cherry red<br>Reddish brown | C—None<br>F—Earthy<br>Brittle | 4.9<br>5.3 | *Red ocher*, earthy; *oolitic*, fish-egg structure; *fossiliferous*, replacement of shells. |
| 2.<br>2.5 | Scarlet<br>Reddish brown | C—Prismatic, not conspicuous<br>F—Uneven<br>Brittle to sectile | 8.<br>8.2 | Color, streak, high specific gravity important; the latter often reduced by gangue. Disseminated in silicious rocks, with native mercury, pyrite, marcasite, realgar, stibnite. |
| 2.5 | Scarlet<br>Aurora red | C—Indistinct<br>F—Conchoidal<br>Brittle | 5.5<br>5.6 | Termed light ruby silver ore. Distinguished from cinnabar by associates. With pyrargyrite, in veins with other silver minerals and galena. |
| 2.5<br>3. | Cherry red<br>Purplish red | C—Indistinct<br>F—Conchoidal<br>Brittle | 5.8 | Frequently as gray or dark red bands, dark ruby silver ore. With proustite, in veins with other silver minerals and galena. |
| 2.5<br>3. | Copper red, shiny | C—None<br>F—Hackly<br>Ductile, malleable | 8.5<br>9. | Cementing material in conglomerate, or filling cavities in trap rocks. With cuprite, malachite, azurite, native silver, melaconite, epidote, datolite, zeolites, quartz, calcite. |

Streak—White, gray, green, red, brown, or yellow

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **LIMONITE**, varieties<br>*Compact*<br>$Fe_2O_3.H_2O$ *Bog iron ore*<br>*Brown clay ironstone*<br>**235** | C—Always pseudomorphs, commonly after pyrite, marcasite, siderite<br>**M**—Compact, stalactitic, botryoidal, nodular; often with internal radial fibrous structure; porous | Metallic<br>Dull<br>Opaque | Yellowish brown<br>Dark brown |
| **Uraninite** (Pitchblende)<br>$UO_3$, $UO_2$, PbO, etc.<br>**262** | Cubic<br>C—Octahedral, rare<br>**M**—Botryoidal, columnar, curved lamellar, granular, compact; apparently amorphous | Submetallic<br>Dull<br>Opaque | Brown<br>Blackish brown |
| **HEMATITE**, varieties<br>*Argillaceous*<br>$Fe_2O_3$ *Compact*<br>**235** | Hexagonal<br>**M**—Compact, granular, columnar, splintery, radiated, reniform and botryoidal | Submetallic<br>Dull<br>Opaque | Brownish red<br>Dark red<br>Blackish red |
| **SIDERITE**<br>$FeCO_3$<br>**248** | Hexagonal<br>C—Rhombohedral, curved or saddle-shaped, common<br>**M**—Cleavable, granular, compact, botryoidal | Dull<br>Vitreous<br>Translucent to opaque | Dark brown<br>Reddish brown |
| **SPHALERITE**<br>ZnS<br>**205** | Cubic<br>C—Tetrahedral, common<br>**M**—Cleavable, fine and coarse grained aggregates, compact | Submetallic<br>Resinous<br>Opaque to translucent | Brown<br>Yellowish brown<br>Reddish brown |

Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.<br>5.5 | Yellowish brown | F—Conchoidal; uneven, earthy<br>Brittle | 3.4<br>4. | Often with black, varnish-like surface, passing into soft, yellow ocherous variety. *Compact limonite*, massive, with fibrous structure, rather pure; *brown clay ironstone* massive or concretionary, impure from clay, sand; *bog iron ore*, porous. |
| 3.<br>5.5<br>Olive green<br>Grayish | Dark brown | F—Conchoidal, uneven<br>Brittle | 4.8<br>9.7 | Structure and fracture important. Fresh material is hard and heavy. With ores of lead, silver, bismuth; also orthite. |
| 3.<br>6. | Cherry red<br>Reddish brown | C—None, parting sometimes noted<br>F—Uneven, splintery<br>Brittle | 4.9<br>5.3 | *Argillaceous hematite*, impure from clay, sand, jasper; *compact hematite*, usually quite pure. |
| 3.5<br>4. | Yellowish brown<br>Pale yellow | C—Rhombohedral, perfect, conspicuous<br>F—Conchoidal<br>Brittle | 3.7<br>3.9 | Curved crystals, cleavage, and rather high specific gravity characteristic. In ore deposits; beds and concretions in limestone and shale. With pyrite, chalcopyrite, galena, tetrahedrite, cryolite. |
| 3.5<br>4. | Light brown<br>Pale yellow | C—Dodecahedral, perfect, conspicuous<br>F—Conchoidal<br>Brittle | 3.9<br>4.2 | Color and streak vary with impurities. Extensively in limestone. With galena, chalcopyrite, pyrite, barite, fluorite, siderite, rhodochrosite. |

Streak—White, gray, green, red, brown, or yellow

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CUPRITE**<br>$Cu_2O$<br>**232** | Cubic<br>**C**—Octahedrons, dodecahedrons, alone or in combination<br>**M**—Compact, granular, earthy; slender crystal aggregates (*chalcotrichite*) | Adamantine<br>Dull<br>Translucent to opaque | Cochineal red<br>Brick red<br>Dark red |
| **Zincite**<br>ZnO<br>**228** | Hexagonal<br>**C**—Hemimorphic, rare<br>**M**—Compact, granular, foliated | Subadamantine<br>Vitreous<br>Translucent to opaque | Dark red<br>Blood red |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long, fibrous, bladed, stalky, often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Submetallic<br>Resinous<br>Opaque to translucent | Reddish brown<br>Brown |
| **WOLFRAMITE**<br>$(Fe,Mn)WO_4$<br>**261** | Monoclinic<br>**C**—Thick, tabular, short columnar, often large<br>**M**—Bladed, curved lamellar, granular, compact | Submetallic<br>Opaque | Reddish brown<br>Dark brown |
| **Ferberite**<br>$FeWO_4$<br>**261** | Monoclinic<br>**C**—Wedge shaped, short prismatic, tabular<br>**M**—Fan shaped aggregates, bladed, granular, compact | Submetallic<br>Opaque | Brown<br>Blackish brown |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.5<br>4. | Brownish red<br>Dirty brown | C—Indistinct<br>F—Uneven<br>Brittle | 5.7<br>6.1 | Characterized by associates, copper minerals—malachite (green) azurite (blue), chalcocite and melaconite (black), chalcopyrite (yellow), native copper. |
| 4.<br>4.5 | Reddish yellow<br>Orange yellow | C—Basal, perfect, usually conspicuous<br>F—Uneven<br>Brittle | 5.4<br>5.7 | Distinguished by associates—calcite, franklinite (black), willemite (yellow to green), rhodonite (flesh red). On exposure becomes coated with the white carbonate. |
| 4.5<br>5.5 | Yellowish brown<br>Greenish gray | C—Clinopinacoidal, perfect, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, specific gravity important. In quartz veins. With fluorite, pyrite, scheelite, wolframite, galena, tetrahedrite. |
| 5.<br>5.5 | Dark red brown | C—Clinopinacoidal, perfect, conspicuous<br>F—Uneven<br>Brittle | 7.1<br>7.5 | Distinguished from huebnerite by streak. Powder may be slightly magnetic. With cassiterite, quartz, mica, fluorite, apatite, scheelite, molybdenite, huebnerite. |
| 5.<br>5.5 | Brown<br>Dark brown | C—Clinopinacoidal, perfect.<br>F—Uneven<br>Brittle | 7.5 | In granites and pegmatites. With quartz, chalcopyrite, galena, scheelite. |

**Streak—White, gray, green, red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Metallic<br>Adamantine<br>Opaque to transparent | Reddish brown<br>Dark red |
| **CASSITERITE,** varieties<br>*Ordinary*<br>*Wood tin*<br>*Stream tin*<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic, knee-shaped twins, common<br>**M**—Compact; reniform, botryoidal, rounded pebbles, often with internal, radial fibrous structure, *wood tin* | Adamantine<br>Resinous<br>Dull<br>Translucent to opaque | Reddish brown<br>Yellowish brown<br>Dark brown |

Hardness over 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>7. | Pale yellowish brown<br>Gray | C—Prismatic, pyramidal, not conspicuous<br>F—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often in fine, hair-like inclusions. Widely distributed. With quartz, feldspar, ilmenite, chlorite, apatite. |
| 6.<br>7. | Pale yellow<br>Pale brown<br>White | C—Indistinct<br>F—Uneven<br>Brittle | 6.8<br>7. | Distinguished by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits, as *stream tin*. With quartz, mica, wolframite, scheelite, arsenopyrite, molybdenite, tourmaline, fluorite, apatite, chlorite. |

Streak—Black

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **BORNITE** (Purple copper ore) $Cu_xFe_2S_{\frac{x}{2}+3}$ $x = 6, 10, 12$ **216** | Cubic<br>**C**—Rare<br>**M**—Compact, granular | Metallic<br>Opaque | Bronze brown<br>Copper red tarnishes readily |
| **Uraninite** (Pitchblende) $UO_3$, $UO_2$, PbO, etc. **262** | Cubic<br>**C**—Octahedral, rare<br>**M**—Botryoidal, columnar, curved lamellar, granular compact, apparently amorphous | Submetallic<br>Dull<br>Opaque | Brown<br>Blackish brown |
| **PYRRHOTITE** FeS **207** | Hexagonal<br>**C**—Tabular, rare<br>**M**—Compact, granular | Metallic<br>Opaque | Bronze brown<br>Bronze yellow |
| **WOLFRAMITE** $(Fe,Mn)WO_4$ **261** | Monoclinic<br>**C**—Thick tabular, short columnar, often large<br>**M**—Bladed, curved lamellar, granular | Submetallic<br>Opaque | Grayish brown<br>Dark brown |
| **Niccolite** NiAs **208** | Hexagonal<br>**C**—Rare<br>**M**—Compact, disseminated | Metallic<br>Opaque | Light copper red |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.** | Grayish black | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 4.9<br>5.2 | Usually with peacock tarnish colors—purple copper ore. With chalcopyrite, chalcocite, malachite, cassiterite, siderite. |
| **3.**<br>**5.5** | Brownish black<br>Grayish black | **F**—Conchoidal, uneven<br>Brittle | 4.8<br>9.7 | Structure and fracture important. Fresh material is hard and heavy. With ores of lead, silver, bismuth; also pyrite, orthite. |
| **3.5**<br>**4.5** | Dark grayish black | **C**—Basal, not conspicuous<br>**F**—Uneven<br>Brittle | 4.5<br>4.6 | Powder frequently attracted by magnet. Subject to dark brown tarnish. In basic igneous rocks. With chalcopyrite, pyrite, galena. |
| **5.5** | Black<br>Brownish black | **C**—Clinopinacoidal, perfect, conspicuous<br>**F**—Uneven<br>Brittle | 7.1<br>7.5 | Structure, cleavage, specific gravity important. Powder may be slightly magnetic. With cassiterite, quartz, mica, fluorite, apatite, scheelite, molybdenite, huebnerite. |
| **5.5** | Dark brownish black | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 7.3<br>7.7 | Often with green crust of annabergite (nickel bloom). With cobalt, nickel, silver minerals—smaltite, proustite, pyrargyrite; native bismuth and arsenic, calcite. |

**Streak—Green, red, brown, yellow, or black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **GRAPHITE** (Plumbago, black lead)<br>C<br>**192** | Hexagonal<br>**C**—Tabular, rare<br>**M**—Scaly, foliated, granular, earthy, sooty | Dull<br>Opaque | Dark gray<br>Iron black |
| **CHLORITE** (Pyrochlorite, clinochlorite)<br>$H_8Mg_5Al_2Si_3O_{18}$?<br>**297** | Monoclinic<br>**C**—Tabular, six-sided, often bent, twisted<br>**M**—Foliated, scaly, granular, earthy | Dull<br>Submetallic<br>Translucent to opaque | Black<br>Greenish black |
| **Uraninite** (Pitchblende)<br>$UO_3$, $UO_2$, PbO, etc.<br>**262** | Cubic<br>**C**—Octahedral, rare<br>**M**—Botryoidal, columnar, curved lamellar, granular, compact, apparently amorphous | Pitch-like<br>Submetallic<br>Dull<br>Opaque | Pitch black<br>Brownish black<br>Greenish black |
| **SIDERITE**<br>$FeCO_3$<br>**248** | Hexagonal<br>**C**—Rhombohedral, curved or saddle-shaped, common<br>**M**—Cleavable, granular, compact, botryoidal | Vitreous<br>Dull<br>Translucent to opaque | Brownish black<br>Black |
| **SPHALERITE** (Black Jack)<br>ZnS<br>**205** | Cubic<br>**C**—Tetrahedral, common<br>**M**—Cleavable, fine and coarse grained, compact | Submetallic<br>Resinous<br>Opaque to translucent | Black<br>Yellowish black<br>Brownish black |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2. | Dark gray<br>Iron black | C—Basal, perfect (scales)<br>Scales flexible | 1.9<br>2.3 | Greasy feel. Marks paper. Often impure. In crystalline limestone with garnet, spinel, pyroxenes, amphiboles; also in shale, gneiss, mica schist. |
| 1.<br>2.5 | Pale green | C—Basal, conspicuous, when foliated<br>F—Scaly, earthy<br>Tough to brittle | 2.6<br>3. | Laminæ flexible but inelastic, with slightly soapy feel. Common in schists and serpentine. With magnetite, magnesite, garnet, diopside. Often as scaly or dusty coating on other minerals. Pseudomorphous after garnet. |
| 3.<br>5.5<br><br><br> | Olive green<br>Dark brown<br>Brownish black<br>Grayish black | F—Conchoidal, uneven<br>Brittle | 4.8<br>9.7 | Pitch-like appearance and fracture characteristic. Fresh material is hard and heavy. With lead, silver, bismuth, minerals; also pyrite, orthite. |
| 3.5<br>4. | Yellowish brown | C—Rhombohedral, perfect, conspicuous<br>F—Conchoidal<br>Brittle | 3.7<br>3.9 | Curved crystals, cleavage, and rather high specific gravity characteristic. In ore deposits; beds and concretions in limestone and shale. With pyrite, chalcopyrite, galena, tetrahedrite, cryolite. |
| 3.5<br>4.<br><br> | Dark brown<br>Yellowish brown<br>Gray | C—Dodecahedral perfect, usually conspicuous<br>F—Conchoidal<br>Brittle | 3.9<br>4.2 | Color and streak vary with impurities. When massive distinguished from siderite by cleavage. Extensively in limestone. With galena, chalcopyrite, pyrite, barite, fluorite, siderite, rhodochrosite. |

**Streak—Green, red, brown, yellow, or black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>C—Long fibrous, bladed, stalky; often divergent, without good terminations<br>M—Compact, lamellar, granular | Resinous<br>Submetallic<br>Translucent to opaque | Brownish black<br>Black |
| **WOLFRAMITE**<br>$(Fe,Mn)WO_4$<br>**261** | Monoclinic<br>C—Thick tabular, short columnar, often large<br>M—Bladed, curved lamellar, granular | Submetallic<br>Opaque | Dark gray<br>Brownish black<br>Iron black |
| **Ferberite**<br>$FeWO_4$<br>**261** | Monoclinic<br>C—Wedge shaped, short prismatic, tabular<br>M—Fan-shaped aggregates, bladed, granular, compact | Submetallic<br>Splendent<br>Opaque | Iron black<br>Brownish black |
| **HORNBLENDE** (Amphibole)<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**312** | Monoclinic<br>C—Long prismatic, prism angle 124°; often with rhombohedral-like terminations<br>M—Bladed, fibrous granular, compact | Vitreous<br>Silky<br>Translucent to opaque | Pitch black<br>Greenish black<br>Brownish black |
| **AUGITE** (Pyroxene)<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**307** | Monoclinic<br>C—Short prismatic; thick columnar, prism angle 87°<br>M—Compact, granular, disseminated | Vitreous<br>Submetallic<br>Translucent to opaque | Pitch black<br>Greenish black<br>Brownish black |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 4.5<br>5.5 | Yellowish brown | C—Clinopinacoidal, perfect, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and high specific gravity characteristic. In quartz veins. With wolframite, fluorite, pyrite, scheelite, galena, tetrahedrite. |
| 5.<br>5.5 | Dark reddish brown<br>Black | C—Clinopinacoidal, perfect, conspicuous<br>F—Uneven<br>Brittle | 7.1<br>7.5 | Distinguished from huebnerite by streak. Powder may be slightly magnetic. With cassiterite, quartz, mica, fluorite, apatite, scheelite, molybdenite, huebnerite. |
| 5.<br>5.5 | Dark brown<br>Brownish black | C—Clinopinacoidal, perfect<br>F—Uneven<br>Brittle | 7.5 | In granites and pegmatites. With quartz, chalcopyrite, galena, scheelite. |
| 5.<br>6. | Grayish green<br>Grayish brown<br>Yellow | C—Prismatic, perfect, often conspicuous—124°<br>Brittle | 2.9<br>3.3 | Simple, pseudohexagonal crystals, and cleavage at 124° important. Very common; in nearly all types of rocks. With calcite, quartz, feldspar, pyroxene, chlorite. |
| 5.<br>6. | Pale green<br>Grayish green | C—Prismatic, perfect, conspicuous—87°<br>Brittle | 3.2<br>3.6 | Crystals usually eight-sided, more rarely four-sided; pseudotetragonal with prism angles of 87° and 93°. Cleavage less distinct than on hornblende. Common in basic eruptive rocks and crystalline limestones. |

**Streak—Green, red, brown, yellow, or black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Psilomelane**<br>$MnO_2$, BaO, $H_2O$, etc.<br>**253** | Amorphous ?<br>**M**—Botryoidal, reniform, stalactitic; smooth surfaces | Submetallic<br>Dull<br>Opaque | Iron black<br>Bluish black<br>Dark gray |
| **CHROMITE**<br>$(Fe,Cr)[(Cr,Fe)O_2]_2$<br>**270** | Cubic<br>**C**—Octahedral, rare<br>**M**—Compact, granular, disseminated grains | Submetallic<br>Pitchy<br>Opaque | Iron black<br>Brownish black |
| **Orthite** (Allanite)<br>$Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$<br>**287** | Monoclinic<br>**C**—Tabular, rare<br>**M**—Compact, granular, bladed, disseminated grains | Submetallic<br>Greasy<br>Translucent to opaque | Black<br>Pitch black<br>Brownish black |

**Streak—Green, red, brown, yellow, or black**

| | | | |
|---|---|---|---|
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Adamantine<br>Metallic<br>Opaque to transparent | Iron black<br>Brownish black<br>Reddish black |
| **CASSITERITE**<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic; knee-shaped twins quite common<br>**M**—Compact, reniform, botryoidal, rounded pebbles, often with internal, radial fibrous structure | Submetallic<br>Dull<br>Translucent to opaque | Black<br>Brownish black |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>6. | Black<br>Brownish black | F—Conchoidal, uneven<br>Brittle | 3.7<br>4.7 | Often with fine sooty coating of pyrolusite. With other manganese minerals; also limonite, barite. |
| 5.5 | Dark brown<br>Grayish brown | C—Indistinct<br>F—Uneven, conchoidal<br>Brittle | 4.3<br>4.6 | May be slightly magnetic. Pitch-like appearance characteristic. With serpentine, talc, chrome garnet; also in black sands, platinum placers. |
| 5.5<br>6. | Pale brown<br>Grayish brown | C—Pinacoidal, indistinct<br>F—Uneven, conchoidal<br>Brittle | 3.<br>4. | Often covered with yellowish or brownish alteration product. Disseminated through the more acid igneous rocks; also in limestones. With magnetite, epidote, quartz, feldspar. |

**Hardness over 6**

| | | | | |
|---|---|---|---|---|
| 6.<br>7. | Pale yellow<br>Pale brown | C—Prismatic, pyramidal, not conspicuous<br>F—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often in fine hairlike inclusions. Widely distributed. With quartz, feldspar, hematite, ilmenite, chlorite. |
| 6.<br>7. | Pale brown<br>Pale yellow | C—Indistinct<br>F—Uneven<br>Brittle | 6.8<br>7. | Distinguished by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits as *stream tin*. With quartz, wolframite, scheelite, arsenopyrite, molybdenite, tourmaline, fluorite, apatite, chlorite, mica. |

**Streak Green, red, brown, yellow or black**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CORUNDUM,** variety *Emery* $Al_2O_3$, with $Fe_3O_4$, $Fe_2O_3$, $SiO_2$ **228** | Hexagonal **M**—Fine to coarse granular | Dull Submetallic Opaque | Dark gray Black |
| **SPINEL,** varieties *Hercynite* *Picotite* $R''(R'''O_2)_2$ $R''$ = Mg, Fe, Zn, Mn $R'''$ = Al, Fe **267** | Cubic **C**—Octahedral, small **M**—Compact, granular, disseminated grains | Vitreous Dull Nearly opaque | Black Brownish black |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **APATITE,** variety *Phosphate rock* $Ca_5F(PO_4)_3$, in part **273** | Hexagonal **M**—Compact, fibrous, nodular, reniform, earthy | Dull Opaque | Black |
| **BIOTITE** Black mica) $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ **294** | Monoclinic **C**—Tabular, with hexagonal or rhombohedral habit **M**—Plates, disseminated scales | Pearly Submetallic Transparent to opaque | Black Brownish black Greenish black |
| **CALCITE,** varieties $CaCO_3$ *Limestone* *Marble* *Stalactites, etc.* *Calcareous tufa* *Travertine* **242** | Hexagonal **M**—Cleavable, granular, fibrous, banded, stalactitic, oolitic, porous, compact, crusts, shells | Vitreous Dull Translucent to opaque | Dark gray Brownish black Black |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 7.<br>9. | Yellowish brown<br>Black | C—Indistinct<br>F—Uneven<br>Brittle to tough | 3.7<br>4.3 | Corundum mixed with iron ore. Powder may be magnetic. With mica, amphibole, chlorite, spinel; in crystalline limestones, schists, peridotites. |
| 7.5<br>8. | Grayish green<br>Pale brown | C—Octahedral, indistinct<br>F—Conchoidal<br>Brittle | 3.9<br>4.1 | Commonly in basic igneous rocks, especially the olivine-bearing types. With olivine, serpentine, corundum, magnetite, hornblende, garnet. |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 2.<br>3. | White | F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | More or less impure masses, frequently resembling compact bituminous limestone. Independent beds, nodules, or concretions. |
| 2.5<br>3. | White<br>Grayish | C—Basal, perfect, conspicuous<br>Tough, lamellæ of fresh biotite very elastic | 2.7<br>3.2 | Easily recognized by structure, highly perfect cleavage, and elasticity. Important constituent of many igneous and metamorphic rocks—granite, syenite, gneiss. |
| 3. | White<br>Gray | C—Rhombohedral, perfect<br>F—Conchoidal<br>Brittle | 2.7 | Rhombohedral cleavage generally observed. Cleavages often striated. Yields bituminous odor when struck with hammer. To distinguish varieties, see reference. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **ANHYDRITE**<br>$CaSO_4$<br>**254** | Orthorhombic<br>**C**—Thick tabular, prismatic, rare<br>**M**—Granular, compact, fibrous, lamellar, cleavable | Vitreous<br>Pearly<br>Translucent to opaque | Dark gray<br>Blackish |
| **SERPENTINE**<br>$H_4Mg_3Si_2O_9$<br>**297** | Orthorhombic ?<br>**C**—Unknown<br>**M**—Compact, columnar, fibrous, lamellar, granular | Greasy<br>Waxy<br>Translucent to opaque | Greenish black<br>Brownish black |
| **APATITE**, variety *Phosphate rock*<br>$Ca_5F(PO_4)_3$, in part<br>**273** | Hexagonal<br>**M**—Compact, fibrous, nodular, reniform, earthy | Dull<br>Opaque | Black |
| **SPHALERITE** (Black Jack)<br>ZnS<br>**205** | Cubic<br>**C**—Tetrahedral, common<br>**M**—Cleavable, fine or coarse grained, compact | Submetallic<br>Opaque to translucent | Black<br>Brownish black<br>Yellowish black |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long fibrous, bladed, stalky often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Resinous<br>Submetallic<br>Translucent to opaque | Brownish black<br>Black |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.**<br>**3.5** | White | C—Pinacoidal, perfect, 3 directions at 90°<br>F—Conchoidal<br>Brittle | 2.8<br>3. | Color due to organic matter. Pseudocubical cleavage sometimes noted. Granular varieties resemble marble. In limestones, shales. With halite, gypsum. |
| **3.**<br>**4.** | White | F—Conchoidal, splintery<br>Brittle | 2.5<br>2.8 | Smooth and greasy feel. Often spotted, clouded, multi-colored. Sometimes crossed by seams of asbestos (chrysotile). With magnesite, calcite, chromite, garnierite, pyrope, platinum. |
| **3.**<br>**5.** | White | F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | More or less impure masses frequently resembling compact, bituminous limestone. Independent beds, nodules, or concretions. |
| **3.5**<br>**4.** | Grayish | C—Dodecahedral perfect, usually conspicuous<br>F—Conchoidal<br>Brittle | 3.9<br>4.2 | Color and streak vary with impurities. Extensively in limestones with galena, chalcopyrite, pyrite, barite, fluorite, siderite, rhodochrosite. |
| **4.5**<br>**5.5** | Greenish gray | C—Clinopinacoidal, perfect, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and specific gravity characteristic. In quartz veins. With wolframite, fluorite, pyrite, scheelite, galena, tetrahedrite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **TITANITE** (Sphene)<br>$CaTiSiO_5$<br>**323** | Monoclinic<br>**C**—Wedge- or envelope-shaped when disseminated; tabular or prismatic when attached<br>**M**—Compact, lamellar | Vitreous<br>Submetallic<br>Translucent to opaque | Black<br>Brownish black |
| **HORNBLENDE** (Amphibole)<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**312** | Monoclinic<br>**C**—Long prismatic, prism angle 124°, often with rhombohedral-like terminations<br>**M**—Bladed, fibrous, granular, compact | Vitreous<br>Silky<br>Translucent to opaque | Pitch black<br>Greenish black<br>Brownish black |
| **AUGITE** (Pyroxene)<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**307** | Monoclinic<br>**C**—Short prismatic, thick columnar, prism angle 87°<br>**M**—Compact, granular, disseminated | Vitreous<br>Submetallic<br>Translucent to opaque | Pitch black<br>Greenish black<br>Brownish black |
| **Orthite** (Allanite)<br>$Ca_2(Al,Ce,Fe)_2(Al.OH)(SiO_4)_3$<br>**287** | Monoclinic<br>**C**—Tabular, rare<br>**M**—Compact, granular, bladed, disseminated grains | Submetallic<br>Greasy<br>Translucent to opaque | Black<br>Pitch black<br>Brownish black |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **LABRADORITE** (Feldspar)<br>Silicate of Na,Ca,Al<br>**321** | Triclinic<br>**C**—Thin tabular, often with rhombic cross-section<br>**M**—Compact, cleavable, granular | Vitreous<br>Pearly<br>Translucent to nearly opaque | Dark gray<br>Greenish gray |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>5.5 | White<br>Gray | C—Prismatic, conspicuous partings often noted<br>F—Conchoidal<br>Brittle | 3.4<br>3.6 | With feldspars, pyroxenes, amphiboles, chlorite, scapolite, zircon. |
| 5.<br>6. | Gray<br>Greenish gray<br>Brownish gray | C—Prismatic, perfect, often conspicuous—124°<br>Brittle | 2.9<br>3.3 | Simple, pseudohexagonal crystals, and cleavage (124°) important. Very common. In nearly all types of rocks. With feldspars, quartz, pyroxenes, chlorite, calcite. |
| 5.<br>6. | White<br>Gray<br>Greenish gray | C—Prismatic, perfect, conspicuous—87°, less distinct than on hornblende.<br>Brittle | 3.2<br>3.6 | Crystals usually eight-sided, more rarely four-sided; pseudotetragonal with prism angles of 87° and 93°. In basic rocks and limestones. |
| 5.5<br>6. | Gray<br>Greenish gray<br>Brownish gray | C—Pinacoidal, indistinct<br>F—Uneven, conchoidal<br>Brittle | 3.<br>4. | Often covered with yellowish or brownish crust. Disseminated in the more acid igneous rocks; limestones. With magnetite, epidote, quartz, feldspars. |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>6.5 | White | C—Basal, brachypinacoidal, perfect, conspicuous—86°<br>F—Uneven, conchoidal<br>Brittle | 2.7 | Often with play of colors—yellow, green, blue, red. Inclined cleavages are striated. In basic igneous rocks. With pyroxenes, amphiboles. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **EPIDOTE**<br>$Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$<br>**286** | Monoclinic<br>**C**—Prismatic, elongated and deeply striated parallel to *b* axis; generally terminated on one end only<br>**M**—Columnar, fibrous, parallel and divergent, granular | Vitreous<br>Translucent to opaque | Greenish black |
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Metallic<br>Adamantine<br>Opaque to translucent | Iron black<br>Brownish black<br>Reddish black |
| **CASSITERITE**<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic, knee-shaped twins, quite common<br>**M**—Compact, reniform, botryoidal, rounded pebbles, often with internal, radial fibrous structure | Submetallic<br>Dull<br>Translucent to opaque | Black<br>Brownish black |
| **GARNET,** varieties<br>*Andradite*<br>$R_3''R_2'''(SiO_4)_3$ *Almandite*<br>R″ = Ca, Fe, Mg<br>R‴ = Al, Fe<br>**290** | Cubic<br>**C**—Dodecahedrons, tetragonal trisoctahedrons, alone or in combination<br>**M**—Granular, compact, lamellar, disseminated, sand | Vitreous<br>Translucent to opaque | Velvety black<br>Brownish black |

Hardness over 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **6.**<br>**7.** | White<br>Grayish | C—Basal, perfect<br>F—Uneven<br>Brittle | 3.3<br>3.5 | Crystals are often dark green or blackish green, massive aggregates lighter colored. Widely distributed. With quartz, feldspar, garnet, hornblende, pyroxene, magnetite, native copper. |
| **6.**<br>**7.** | Gray<br>Yellowish white<br>Brownish white | C—Prismatic, pyramidal, not conspicuous<br>F—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often in hair-like inclusions. Widely distributed. With quartz, feldspar, hematite, ilmenite, chlorite. |
| **6.**<br>**7.** | White<br>Yellowish white<br>Brownish white | C—Indistinct<br>F—Uneven<br>Brittle | 6.8<br>7. | Distinguished by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits as *stream tin*. With quartz, wolframite, scheelite, molybdenite, tourmaline, fluorite, mica, chlorite. |
| **6.5**<br>**7.5** | White | C—Dodecahedral, usually indistinct<br>F—Conchoidal, uneven<br>Brittle | 3.8<br>4.2 | *Andradite*, commonly with magnetite, epidote, feldspars, nephelite, leucite; *almandite*, with mica, staurolite, andalusite, cyanite, tourmaline. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **QUARTZ,** $SiO_2$ Phanerocrystalline variety *Smoky quartz* | Hexagonal **C**—Prismatic, horizontally striated **M**—Compact, granular | Vitreous Transparent to translucent | Grayish black Brownish black |
| Cryptocrystalline varieties *Chalcedony* *Onyx* *Flint* **220** | Hexagonal Fine crystalline masses, banded, nodular, botryoidal, stalactitic | Waxy Vitreous Translucent to opaque | Grayish black Brownish black Velvet black |
| **TOURMALINE** $M_9'Al_3(B.OH)_2Si_4O_{19}$ M′ = Na, K, Li, Mg, Fe **284** | Hexagonal **C**—Prismatic, vertically striated; terminated with broken or rhombohedral-like surfaces; well developed crystals are hemimorphic **M**—Compact, divergent columnar | Pitchy Vitreous Translucent to opaque | Pitch black Brownish black Bluish black |
| **STAUROLITE** $Fe(AlO)_4(Al.OH)(SiO_4)_2$ **279** | Orthorhombic **C**—Prismatic; twins plus (+) or X-shaped, well developed, often large | Vitreous Dull Translucent to opaque | Brownish black Dark gray |
| **SPINEL,** varieties *Pleonaste* *Gahnite* *Dysluite* $R''(R'''O_2)_2$ R″ = Mg, Fe, Zn, Mn R‴ = Al, Fe **267** | Cubic **C**—Octahedral, well developed, common **M**—Compact, granular, disseminated grains | Vitreous Dull Nearly opaque | Brownish black Grayish black Greenish black |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **7.** | White | **C**—Indistinct<br>**F**—Conchoidal, conspicuous<br>Brittle | 2.6 | Characteristic conchoidal fracture and glassy luster. Common in granitic rocks. |
| **7.** | White | **C**—Indistinct<br>**F**—Conchoidal, conspicuous<br>Brittle to tough | 2.6 | Conchoidal fracture characteristic. *Chalcedony*, waxy luster; *onyx*, banded; *flint*, generally with white coating; *basanite*, velvet black. |
| **7.**<br>**7.5** | White<br>Gray | **C**—None<br>**F**—Conchoidal, uneven<br>Brittle | 2.9<br>3.2 | Spherical triangular cross-section, coal black color, and lack of cleavage important. In pegmatites; metamorphic rocks; alluvial deposits. With quartz, feldspar, cassiterite, beryl, topaz, fluorite. |
| **7.**<br>**7.5** | White<br>Gray | **C**—Brachypinacoidal<br>**F**—Conchoidal, uneven<br>Brittle | 3.4<br>3.8 | Fresh crystals usually possess bright and smooth faces, when altered dull, rough, softer, and with colored streak. In metamorphic rocks—gneiss, mica schist, slate. With cyanite, garnet, tourmaline, sillimanite. |
| **7.5**<br>**8.** | White<br>Grayish | **C**—Octahedral, indistinct<br>**F**—Conchoidal | 3.6<br>4.4 | Commonly as contact mineral in granular limestones; in more basic igneous rocks; rounded grains in placers. With calcite, chondrodite, serpentine, corundum, graphite, pyroxene, phlogopite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **DIAMOND,** varieties<br>*Diamond proper*<br>*Bort*<br>*Carbonado*<br>C<br>**188** | Cubic<br>C—Octahedrons, hexoctahedrons, usually with curved surfaces<br>M—Rounded or irregular grains or pebbles, often with radial structure | Adamantine<br>Vitreous<br>Translucent to opaque | Black<br>Dark gray |

B. MINERALS WITH NON-METALLIC LUSTER

**Streak—Red, brown, or yellow**

| | | | |
|---|---|---|---|
| **BAUXITE**<br>$Al_2O(OH)_4$<br>**235** | Never in crystals<br>M—Pisolitic, oolitic, rounded disseminated grains, clay-like, earthy | Dull<br>Earthy<br>Opaque | Red<br>Reddish brown |
| **HEMATITE,** varieties<br>*Red ocher*<br>*Oolitic*<br>*Fossiliferous*<br>$Fe_2O_3$<br>**230** | Hexagonal<br>M—Fine granular, earthy, oolitic, replacement of shells | Dull<br>Opaque | Brownish red<br>Cherry red |
| **REALGAR**<br>AsS<br>**203** | Monoclinic<br>C—Short prismatic, rare<br>M—Granular, compact, incrustations | Resinous<br>Transparent to translucent | Aurora red<br>Orange yellow |
| **CINNABAR**<br>HgS<br>**215** | Hexagonal<br>C—Rhombohedral, thick tabular, small<br>M—Fine granular, fibrous, earthy coatings | Adamantine<br>Dull<br>Transparent to opaque | Scarlet red<br>Brownish red |

### Hardness over 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **10.** | Ash gray | **C**—Octahedral, perfect (diamond proper)<br>**F**—Conchoidal<br>Brittle | 3.1<br>3.5 | *Diamond proper*, crystals and cleavage fragments; *bort*, translucent with radial structure, also crystal fragments; *carbonado*, granular to compact, opaque. In serpentine rocks—kimberlite—called *blue ground*, in placers. With pyrope, magnetite, chromite, zircon. |

## 2. PINK, RED, OR RED VIOLET IN COLOR

### Hardness 1 to 3

| | | | | |
|---|---|---|---|---|
| **1.**<br>**3.** | Reddish<br>Yellowish | **F**—Earthy<br>Brittle | 2.5<br>2.6 | Color and streak variable. Clay odor when breathed upon. Distinguished from clay by structure. With clay or kaolinite in nodules, grains, or irregular deposits in limestone or dolomite. |
| **1.**<br>**3.** | Cherry red<br>Reddish brown | **C**—None<br>**F**—Earthy<br>Brittle | 4.9<br>5.3 | *Red ocher*, red earthy variety; *oolitic hematite*, fish-egg structure; *fossiliferous hematite*, replacement of shells. |
| **1.5**<br>**2.** | Orange yellow | **C**—Clinopinacoidal, basal<br>**F**—Conchoidal<br>Slightly sectile | 3.4<br>3.6 | Frequently disseminated in clay or dolomite. With orpiment, stibnite, native arsenic, pyrite, barite, calcite. |
| **2.**<br>**2.5** | Scarlet<br>Red brown | **C**—Prismatic, not conspicuous<br>**F**—Uneven<br>Brittle to sectile | 8.<br>8.2 | Characterized by color, streak, and high specific gravity. Disseminated through silicious rocks. With native mercury, pyrite, marcasite, realgar, stibnite. |

**Streak—Red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Proustite**<br>$Ag_3AsS_3$<br>**217** | Hexagonal<br>**C**—Small, complex, rare<br>**M**—Compact, disseminated, crusts, bands | Adamantine<br>Dull<br>Translucent to transparent | Scarlet<br>Vermilion |
| **Crocoite**<br>$PbCrO_4$<br>**258** | Monoclinic<br>**C**—Prismatic, acicular<br>**M**—Columnar, granular, crusts | Adamantine<br>Greasy<br>Translucent | Hyacinth red<br>Aurora red |
| **Pyrargyrite**<br>$Ag_3SbS_3$<br>**217** | Hexagonal<br>**C**—Small, complex, rare<br>**M**—Compact, disseminated, crusts, bands | Adamantine<br>Metallic<br>Transparent to opaque | Dark red |
| **Wulfenite**<br>$PbMoO_4$<br>**259** | Tetragonal<br>**C**—Square, thin tabular, more rarely pyramidal<br>**M**—Coarse, fine granular | Resinous<br>Adamantine<br>Transparent to translucent | Orange red<br>Bright red |
| **Vanadinite**<br>$Pb_5Cl(VO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, small, at times skeletal<br>**M**—Compact, globular, fibrous, crusts | Resinous<br>Translucent to opaque | Ruby red<br>Brownish red<br>Orange red |

**Streak—Red, brown, or yellow**

| | | | | |
|---|---|---|---|---|
| **HEMATITE,** varieties<br>$Fe_2O_3$<br>**230** | *Argillaceous*<br>*Compact* | Hexagonal<br>**M**—Compact, granular, columnar, splintery, radiated reniform or botryoidal | Submetallic<br>Dull<br>Opaque | Brownish red<br>Dark red |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **2.5** | Scarlet<br>Aurora red | C—Imperfect<br>F—Conchoidal<br>Brittle | 5.5<br>5.6 | *Light ruby silver ore.* Distinguished from cinnabar by associates. With pyrargyrite, in veins with other silver minerals and galena. Compare pyrargyrite. |
| **2.5** | Orange yellow | C—Basal, prismatic<br>F—Conchoidal, uneven<br>Sectile | 5.9<br>6.1 | Resembles potassium bichromate in color. Alteration product of galena. With galena, quartz, pyrite, vanadinite, wulfenite. |
| **2.5**<br>**3.** | Cherry red<br>Purplish red | C—Indistinct<br>F—Conchoidal<br>Brittle | 5.8 | Frequently as gray or dark red bands. Darker than proustite—*dark ruby silver ore.* With proustite, in veins with other silver minerals and galena. |
| **3.** | Lemon yellow<br>Pale yellow | C—Pyramidal, indistinct<br>F—Conchoidal, uneven<br>Brittle | 6.3<br>**7.** | Square plates, sometimes with forms of the third order. With lead minerals—galena, pyromorphite, vanadinite. |
| **3.** | Pale yellow<br>Yellow | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.7<br>7.2 | Crystal faces smooth with sharp edges. With lead minerals but never in large quantities. |

**Hardness over 3**

| | | | | |
|---|---|---|---|---|
| **3.**<br>**6.** | Cherry red<br>Reddish brown | C—None<br>F—Uneven, splintery<br>Brittle | 4.9<br>5.3 | *Argillaceous hematite*, impure from clay, sand, jasper; *compact hematite*, usually quite pure. |

**Streak—Red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **SPHALERITE**<br>ZnS<br>**205** | Cubic<br>**C**—Tetrahedral, common<br>**M**—Cleavable, fine to coarse granular, compact | Greasy<br>Submetallic<br>Translucent to opaque | Brownish red<br>Yellowish red |
| **CUPRITE**<br>$Cu_2O$<br>**232** | Cubic<br>**C**—Octahedrons, dodecahedrons, alone or in combination<br>**M**—Compact, granular, earthy; slender crystal aggregates (*chalcotrichite*) | Adamantine<br>Dull<br>Translucent to opaque | Cochineal red<br>Brick red<br>Dark red |
| **Zincite**<br>ZnO<br>**228** | Hexagonal<br>**C**—Hemimorphic, rare<br>**M**—Compact, granular, foliated | Adamantine<br>Vitreous<br>Translucent to opaque | Dark red<br>Blood red |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long, fibrous, bladed, stalky; often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Greasy<br>Submetallic<br>Translucent to opaque | Brownish red |
| **WOLFRAMITE**<br>$(Fe,Mn)WO_4$<br>**261** | Monoclinic<br>**C**—Thick tabular, short columnar, often large<br>**M**—Bladed, curved lamellar, granular, compact | Submetallic<br>Opaque | Brownish red |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.5**<br>**4.** | Pale yellow<br>Brownish yellow | **C**—Dodecahedral, perfect, usually conspicuous<br>**F**—Conchoidal<br>Brittle | 3.9<br>4.2 | Color and streak vary with impurities. Extensively in limestone. With galena, chalcopyrite, pyrite, barite, fluorite, siderite, rhodochrosite. |
| **3.5**<br>**4.** | Brownish red<br>Dirty brown | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 5.7<br>6.1 | Characterized by associates, usually with copper minerals—malachite (green), azurite (blue), chalcocite and melaconite (black), chalcopyrite (yellow), native copper. |
| **4.**<br>**4.5** | Orange yellow<br>Reddish yellow | **C**—Basal, sometimes conspicuous<br>**F**—Uneven<br>Brittle | 5.4 | Associates important—calcite, franklinite (black), willemite (yellow to green), rhodonite (flesh red). On exposure becomes coated with the white carbonate. |
| **4.5**<br>**5.5** | Yellowish brown | **C**—Clinopinacoidal, perfect, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and specific gravity characteristic. In quartz veins. With wolframite, fluorite, scheelite, galena, tetrahedrite. |
| **5.**<br>**5.5** | Dark reddish brown | **C**—Clinopinacoidal, perfect, conspicuous<br>**F**—Uneven<br>Brittle | 7.1<br>7.5 | Distinguished from huebnerite by streak. Powder may be slightly magnetic. With cassiterite, quartz, mica, scheelite, molybdenite, huebnerite. |

**Streak—Red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Adamantine<br>Submetallic<br>Translucent to opaque | Dark red<br>Brownish red |
| **CASSITERITE**<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic; knee-shaped twins quite common<br>**M**—Compact, reniform, botryoidal, rounded pebbles, often with radial fibrous structure (*wood tin*) | Adamantine<br>Dull<br>Translucent to opaque | Brownish red<br>Yellowish red |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **GYPSUM**<br>$CaSO_4.2H_2O$<br>**264** | Monoclinic<br>**C**—Rare<br>**M**—Coarse, fine granular, fibrous, cleavable, sand | Vitreous<br>Silky<br>Dull<br>Transparent to opaque | Flesh red<br>Brick red |
| **HALITE** (Rock salt)<br>NaCl<br>**236** | Cubic<br>**C**—Cubes, often skeletal or hopper-shaped, rare<br>**M**—Compact, cleavable, granular, fibrous, crusts, stalactitic | Vitreous<br>Transparent to translucent | Red<br>Reddish<br>Purplish |
| **Lepidolite** (Lithium mica)<br>$(Li,H)_2(F,OH)_2Al_2Si_3O_9$<br>**297** | Monoclinic<br>**C**—Short prismatic<br>**M**—Granular, coarse or fine; scales, cleavable plates | Pearly<br>Translucent | Pink<br>Rose red<br>Red violet |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **6.**<br>**6.5** | Yellowish<br>Brownish | **C**—Prismatic, pyramidal, not conspicuous<br>**F**—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often in fine, hair-like inclusions. Widely distributed. With quartz, feldspars, hematite, ilmenite, chlorite. |
| **6.**<br>**7.** | Pale yellow<br>Pale brown | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 6.8<br>7. | Recognized by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits as *stream tin.* With quartz, wolframite, scheelite, arsenopyrite, tourmaline, fluorite, apatite, chlorite, mica. |

**Hardness 1 to 3**

| | | | | |
|---|---|---|---|---|
| **1.5**<br>**2.** | White | **C**—Clinopinacoidal, perfect conspicuous; pyramidal, orthopinacoidal (crystals)<br>**F**—Conchoidal<br>Brittle, laminæ flexible | 2.2<br>2.4 | Ferruginous gypsum. In limestones, shales. With halite, celestite, sulphur, aragonite, anhydrite, ore deposits. |
| **2.**<br>**2.5** | White | **C**—Cubic, perfect, conspicuous<br>**F**—Conchoidal<br>Brittle | 2.1<br>2.3 | Characteristic cubical cleavage and saline taste. Color due to impurities. May absorb moisture and become damp. With shale, gypsum, anhydrite. |
| **2.**<br>**3.** | White | **C**—Basal, perfect<br>**F**—Scaly, granular<br>Tough | 2.8<br>2.9 | When massive may resemble granular limestone. In pegmatites, granites, gneisses. With red tourmaline (rubellite), amblygonite, spodumene, topaz. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **PHLOGOPITE** (Bronze mica)<br>$(K,H)_3Mg_3Al(SiO_4)_3$<br>**294** | Monoclinic<br>**C**—Tabular, prismatic, hexagonal or orthorhombic outline, often large and coarse<br>**M**—Plates, disseminated scales | Pearly<br>Submetallic<br>Transparent to translucent | Copper red<br>Bronze red<br>Brownish red |
| **CALCITE**<br>$CaCO_3$<br>**242** | Hexagonal<br>**C**—Scalenohedral, rhombohedral, prismatic, tabular, often highly modified, twinned<br>**M**—Cleavable, granular, fibrous, compact | Vitreous<br>Dull<br>Transparent to nearly opaque | Pink<br>Red<br>Violet<br>Amethystine |
| **Wulfenite**<br>$PbMoO_4$<br>**259** | Tetragonal<br>**C**—Square, thin tabular, more rarely pyramidal<br>**M**—Coarse to fine granular | Greasy<br>Adamantine<br>Transparent to translucent | Orange red<br>Bright red |
| **Vanadinite**<br>$Pb_5Cl(VO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, small, at times skeletal<br>**M**—Compact, globular, fibrous, crusts | Greasy<br>Translucent to opaque | Ruby red<br>Orange red<br>Brownish red |

**Streak—Uncolored, white or light gray**

| | | | |
|---|---|---|---|
| **STILBITE** (Zeolite)<br>$(Ca,Na_2)Al_2Si_6O_{16}.6H_2O$<br>**326** | Monoclinic<br>**C**—Twinned in sheaf-like, radial, or globular aggregates | Vitreous<br>Pearly<br>Transparent to translucent | Pale red<br>Brick red |
| **Lepidolite** (Lithium mica)<br>$(Li,H)_2(F,OH)_2Al_2Si_3O_9$<br>**297** | Monoclinic<br>**C**—Short prismatic<br>**M**—Granular, coarse or fine; scales, cleavable plates | Pearly<br>Translucent | Pink<br>Rose red<br>Red violet |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **2.5**<br>**3.** | White | C—Basal, perfect, conspicuous<br>Tough, laminæ very elastic | 2 8<br>3. | When cleavage laminæ are held close to the eye in viewing a source of light, a star-like form is sometimes observed. Characteristic of crystalline limestones, dolomites, schists. With pyroxenes, amphiboles, serpentine. |
| **3.** | White | C—Rhombohedral, perfect, very conspicuous<br>F—Conchoidal<br>Brittle | 2.7 | Rhombohedral cleavage characteristic, especially on crystals. Cleavages often show striations. Very strong double refraction observed when transparent. |
| **3.** | White<br>Yellowish white | C—Pyramidal, indistinct<br>F—Conchoidal, uneven<br>Brittle | 6.3<br>7. | Square plates, sometimes with forms of the third order. With lead minerals—galena, pyromorphite, vanadinite. |
| **3.** | White<br>Yellowish white | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.7<br>7.2 | Crystal faces smooth with sharp edges. With lead minerals but never in large quantities. |

**Hardness 3 to 6**

| | | | | |
|---|---|---|---|---|
| **3.**<br>**4.** | White | C—Pinacoidal<br>F—Uneven<br>Brittle | 2 1<br>2 2 | Radial and sheaf-like structure important. In basic igneous rocks, ore deposits. With chabazite, apophyllite, datolite ealcite, |
| **3.**<br>**4.** | White | C—Basal, perfect<br>F—Scaly, granular<br>Tough | 2 8<br>2.9 | When massive often like granular limestone. In pegmatites, granites, gneisses. With red tourmaline (rubellite), amblygonite, spodumene, topaz. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **ALUNITE** (Alum stone)<br>$K_2(Al.2OH)_6(SO_4)_4$<br>**262** | Hexagonal<br>**C**—Rhombohedrons, resembling cubes; tabular, rare<br>**M**—Compact, granular, fibrous, earthy | Vitreous<br>Pearly<br>Transparent to translucent | Pink<br>Reddish white |
| **SPHALERITE**<br>ZnS<br>**205** | Cubic<br>**C**—Tetrahedral, common<br>**M**—Cleavable, fine or coarse granular, compact | Greasy<br>Submetallic<br>Translucent to opaque | Brownish red<br>Yellowish red |
| **RHODOCHROSITE**<br>$MnCO_3$<br>**248** | Hexagonal<br>**C**—Rhombohedral, rare<br>**M**—Cleavable, granular, compact, botryoidal, crusts | Vitreous<br>Translucent | Rose red<br>Brownish red<br>Pink |
| **FLUORITE** (Fluor spar)<br>$CaF_2$<br>**239** | Cubic<br>**C**—Cubes, alone or modified, well developed, common; penetration twins<br>**M**—Cleavable, granular, fibrous | Vitreous<br>Transparent to nearly opaque | Red violet<br>Pink<br>Rose red |
| **CHABAZITE** (Zeolite)<br>$CaAl_2Si_6O_{16}.8H_2O$, etc.<br>**327** | Hexagonal<br>**C**—Rhombohedral, cube-like, lenticular<br>**M**—Compact | Vitreous<br>Translucent to transparent | Flesh red<br>Red |
| **APOPHYLLITE** (Zeolite)<br>$H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$<br>**326** | Tetragonal<br>**C**—Prismatic, pyramidal, pseudocubical, tabular<br>**M**—Lamellar, granular, compact | Vitreous<br>Pearly<br>Transparent to nearly opaque | Pale red<br>Flesh red<br>Rose red |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.5**<br>**4.** | White | **C**—Basal<br>**F**—Splintery, conchoidal, earthy<br>Brittle | 2.6<br>2.8 | Hardness often greater due to admixture of quartz, feldspar, then tough. Deposits and veins in feldspathic rocks. With kaolin, pyrite, opal. |
| **3.5**<br>**4.** | Gray<br>Yellowish white | **C**—Dodecahedral, perfect, usually conspicuous<br>**F**—Conchoidal<br>Brittle | 3.9<br>4.2 | Color and streak vary with impurities. Extensively in limestones. With galena, chalcopyrite, pyrite, barite, fluorite, rhodochrosite. |
| **3.5**<br>**4.5** | White | **C**—Rhombohedral, perfect, conspicuous<br>**F**—Uneven<br>Brittle | 3.3<br>3.6 | May turn brown to black on exposure, due to $MnO_2$. With galena, sphalerite, pyrite, rhodonite, psilomelane, silver minerals. |
| **4.** | White | **C**—Octahedral, perfect, conspicuous<br>Brittle | 3.<br>3.2 | Easily recognized by crystal form, cleavage, and hardness. Common gangue mineral of metallic ores. With galena, sphalerite, cassiterite, calcite, quartz, barite. |
| **4.**<br>**5** | White | **C**—Rhombohedral, not conspicuous<br>**F**—Uneven<br>Brittle | 2.1<br>2.2 | Generally in cube-like crystals. Inferior cleavage distinguishes it from fluorite and calcite. In basic igneous rocks. With analcite, stilbite. |
| **4.5**<br>**5** | White | **C**—Basal, perfect, conspicuous<br>**F**—Uneven<br>Brittle | 2.3<br>2.4 | Prism faces vertically striated. In fissures and cavities in basic igneous rocks. With natrolite, analcite, datolite, pectolite, native copper, calcite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **APATITE**<br>$Ca_5F(PO_4)_3$<br>**273** | Hexagonal<br>**C**—Prismatic, thick tabular, common, sometimes large with rounded edges<br>**M**—Compact, fibrous, nodular, reniform | Greasy<br>Vitreous<br>Translucent to opaque | Violet red<br>Brownish red<br>Red |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long fibrous, bladed, stalky; often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Resinous<br>Submetallic<br>Translucent to opaque | Brownish red |
| **ANALCITE** (Zeolite)<br>$Na_2Al_2(SiO_3)_4.2H_2O$<br>**325** | Cubic<br>**C**—Tetragonal trisoctahedrons, cubes<br>**M**—Granular, compact | Vitreous<br>Translucent to opaque | Reddish<br>Brick red |
| **Datolite**<br>$Ca(B.OH)SiO_4$<br>**283** | Monoclinic<br>**M**—Compact, fibrous, granular, botryoidal | Vitreous<br>Greasy<br>Dull<br>Translucent to opaque | Pink<br>Red<br>Red violet |
| **TITANITE** (Sphene)<br>$CaTiSiO_5$<br>**323** | Monoclinic<br>**C**—Wedge- or envelope-shaped when disseminated; tabular or prismatic when attached<br>**M**—Compact, lamellar | Vitreous<br>Greasy<br>Transparent to opaque | Brownish red<br>Red |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 4.5<br>5. | White<br>Reddish white | C—Basal, imperfect<br>F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | Crystals may be vertically striated and have fused appearance. Color often unevenly distributed,—mottled brown and green. In crystalline limestones, metalliferous ore deposits, igneous rocks. With quartz, cassiterite, fluorite, wolframite, magnetite. |
| 4.5<br>5.5 | Greenish gray | C—Clinopinacoidal, perfect, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and specific gravity characteristic. In quartz veins. With wolframite, fluorite, pyrite, scheelite, galena, tetrahedrite. |
| 5.<br>5.5 | White<br>Reddish white | C—None<br>F—Uneven, conchoidal<br>Brittle | 2.2<br>2.3 | Good crystals common. In fissures and cavities in basic igneous rocks. With apophyllite, chabazite, natrolite, datolite, native copper, epidote. |
| 5.<br>5.5 | White | C—None<br>F—Conchoidal, uneven<br>Brittle | 2.9<br>3. | Compact masses often with brownish, yellowish, or whitish streaks and spots. In cracks and cavities in basic igneous rocks. With calcite, epidote, native copper, zeolites. |
| 5.<br>5.5 | White<br>Gray | C—Prismatic, conspicuous parting often noted<br>F—Conchoidal<br>Brittle | 3.4<br>3.6 | With feldspars, pyroxenes, amphiboles, chlorite, scapolite, zircon. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Monazite**<br>$(Ce,La,Di)PO_4$<br>**272** | Monoclinic<br>**C**—Thick tabular, square prismatic<br>**M**—Angular, rolled grains | Resinous<br>Vitreous<br>Translucent to opaque | Hyacinth red<br>Brownish red |
| **SCAPOLITE** (Wernerite)<br>$\left\{ \begin{matrix} n Na_4Al_3Si_9O_{24}Cl \\ m Ca_4Al_6Si_6O_{25} \end{matrix} \right.$<br>**322** | Tetragonal<br>**C**—Prismatic<br>**M**—Compact, granular, fibrous, columnar | Vitreous<br>Greasy<br>Translucent | Pink<br>Red violet<br>Brick red |
| **RHODONITE** (Pyroxene)<br>$MnSiO_3$<br>**309** | Triclinic<br>**C**—Tabular, prismatic, rounded edges, often large<br>**M**—Compact, cleavable, granular, disseminated grains | Vitreous<br>Dull<br>Transparent to opaque | Brownish red<br>Flesh red<br>Rose red |
| **OPAL,** varieties<br>*Fire opal*<br>*Opal jasper*<br>$SiO_2.xH_2O$<br>**232** | Amorphous<br>**M**—Reniform, botryoidal, stalactitic, compact | Vitreous<br>Greasy<br>Transparent to opaque | Red<br>Brownish red |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **ORTHOCLASE** (Feldspar)<br>$KAlSi_3O_8$<br>**316** | Monoclinic<br>**C**—Prismatic, thick tabular, twins; often large<br>**M**—Cleavable, granular, disseminated | Vitreous<br>Pearly<br>Translucent to opaque | Flesh red<br>Brick red |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.**<br>**5.5** | White | **C**—Basal<br>**F**—Conchoidal, uneven<br>Brittle | 4.9<br>5.3 | Crystals commonly small, highly modified, or as rolled grains in sand. With magnetite, zircon, garnet, gold, chromite, diamond. |
| **5.**<br>**6.** | White | **C**—Prismatic, not conspicuous<br>**F**—Conchoidal<br>Brittle | 2.6<br>2.8 | Often resembles pink fluorite in color, but cleavage less distinct, and harder. In metamorphic rocks, especially granular limestones. With pyroxenes, apatite, garnet, titanite, biotite, amphiboles. |
| **5.**<br>**6.** | White<br>Reddish white | **C**—Prismatic, basal<br>**F**—Conchoidal, uneven<br>Tough, when massive; crystals brittle | 3.4<br>3.7 | May be stained brown to black on exposure. *Fowlerite*, variety containing zinc. With franklinite, zincite, willemite, calcite, tetrahedrite. |
| **5.5**<br>**6.** | White | **F**—Conchoidal, conspicuous<br>Brittle | 2.1<br>2.3 | Structure and fracture characteristic. *Fire opal*, transparent to translucent and red; *opal jasper*, greasy and opaque, resembling jasper. In veins, cavities, and masses of irregular outline. |

**Hardness over 6**

| | | | | |
|---|---|---|---|---|
| **6.**<br>**6.5** | White | **C**—Basal, clinopinacoidal, perfect, conspicuous—90°<br>**F**—Conchoidal, uneven<br>Brittle | 2.5<br>2.6 | Characterized by rectangular cleavage and absence of twinning striations. In granitic rocks. With quartz, other feldspars, mica, hornblende, zircon. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Chondrodite**<br>$[Mg(F,OH)]_2Mg_3(SiO_4)_2$<br>**286** | Monoclinic<br>**C**—Small, highly modified, rare<br>**M**—Rounded, disseminated grains; compact | Vitreous<br>Greasy<br>Translucent to opaque | Brownish red<br>Dark red |
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Adamantine<br>Submetallic<br>Translucent to opaque | Dark red<br>Brownish red |
| **CASSITERITE**<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic; knee-shaped twins quite common<br>**M**—Compact, reniform, botryoidal, rounded pebbles, often with internal, radial fibrous structure, *wood tin* | Adamantine<br>Resinous<br>Dull<br>Translucent to opaque | Brownish red<br>Yellowish red |
| **ANDALUSITE**<br>$Al_2SiO_5$<br>**281** | Orthorhombic<br>**C**—Prismatic, rough, nearly square, often large and without terminations<br>**M**—Columnar, fibrous, granular, disseminated | Vitreous<br>Dull<br>Translucent opaque | Pink<br>Rose red<br>Red violet |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **6.**<br>**6.5** | White | **C**—Basal<br>**F**—Conchoidal, uneven<br>Brittle | 3.1<br>3.3 | Associates important. Chiefly in crystalline limestones and dolomites. With spinel, vesuvianite, pyroxenes, magnetite, mica. |
| **6.**<br>**7.** | Gray<br>Yellowish white<br>Brownish white | **C**—Prismatic, pyramidal, not conspicuous<br>**F**—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often as fine hair-like inclusions. Widely distributed. With quartz, feldspar, hematite, ilmenite, chlorite. |
| **6.**<br>**7.** | White<br>Yellowish white<br>Brownish white | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 6.8<br>7. | Distinguished by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits as *stream tin*. With quartz, wolframite, scheelite, arsenopyrite, tourmaline, fluorite, mica, chlorite. |
| **6.**<br>**7.5** | White | **C**—Prismatic<br>**F**—Uneven<br>Brittle | 3.1<br>3.2 | Due to alteration, surface may be covered with scales of mica and, hence, is softer. In metamorphic rocks often as rounded or knotty projections. With cyanite, sillimanite, garnet, tourmaline. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **GARNET,** varieties<br>*Grossularite*<br>$R_3''R_2'''$<br>$(SiO_4)_3$<br>*Pyrope*<br>R″ = Ca,<br>*Spessartite*<br>Fe,Mg<br>*Almandite*<br>R‴ = Al,Fe<br>*Andradite*<br>**290** | Cubic<br>**C**—Dodecahedrons, tetragonal trisoctahedrons, alone or in combination<br>**M**—Granular, compact, lamellar, disseminated, sand | Vitreous<br>Transparent to opaque | Rose red<br>Ruby red<br>Brownish red<br>Dark red |
| **QUARTZ,** Phanerocrystalline varieties<br>$SiO_2$<br>*Amethyst*<br>*Rose quartz*<br>*Aventurine*<br>*Ferruginous*<br>**220** | Hexagonal<br>**C**—Prismatic, horizontally striated, common<br>**M**—Compact, granular | Vitreous<br>Greasy<br>Transparent to opaque | Red violet<br>Rose red<br>Brick red<br>Brownish red |
| Cryptocrystalline varieties<br>*Carnelian*<br>*Agate*<br>*Sard*<br>*Jasper*<br>*Heliotrope* | Hexagonal<br>**C**—Never in crystals<br>**M**—Banded, spotted, compact | Waxy<br>Vitreous<br>Translucent to opaque | Bright red<br>Dark red<br>Brownish red |
| Clastic varieties<br>*Sand*<br>*Sandstone*<br>*Quartzite* | Hexagonal<br>Loose or strongly consolidated grains or fragments | Vitreous<br>Dull<br>Translucent to opaque | Red<br>Brownish red<br>Purplish red |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **6.5**<br>**7.5** | White<br>Gray | C—Dodecahedral, indistinct<br>F—Conchoidal, uneven<br>Brittle | 3.4<br>4.3 | *Grossularite*, in crystalline limestones and dolomites, with wollastonite, vesuvianite, diopside, scapolite; *pyrope*, rounded grains, in serpentine; *spessartite*, in granitic rocks, with topaz, tourmaline, quartz, orthoclase; *almandite*, with mica, staurolite, andalusite, cyanite; *andradite*, with magnetite, epidote, feldspar, nephelite, leucite. |
| **7.** | White<br>Reddish white | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle | 2.6 | Characteristic conchoidal fracture and glassy luster. *Amethyst*, usually in crystals, purple or blue violet; *rose quartz*, usually massive, pink to rose red; *aventurine*, massive and glistening, due to included scales; *ferruginous quartz*, colored by iron oxide. |
| **7.** | White<br>Reddish white | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle to tough | 2.6 | Not as glassy as phanerocrystalline varieties. *Carnelian*, *jasper*, uniform in color; *agate*, *sardonyx*, banded; *heliotrope*, spotted. To distinguish, see reference. |
| **7.** | White<br>Reddish white | C—Indistinct<br>F—Uneven<br>Brittle to tough | 2.6 | Pigment is usually ferruginous matter. *Sand*, loose, unconsolidated grains; *sandstone*, consolidated sand; *quartzite*, metamorphosed sandstone. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **TOURMALINE,** variety<br>*Rubellite*<br>$M_9'Al_3(B.OH)_2Si_4O_{19}$<br>M′ = Na,K,Li,Mg,Fe<br>**284** | Hexagonal<br>**C**—Prismatic, often vertically striated, rarely with good terminations<br>**M**—Divergent, columnar, compact | Vitreous<br>Transparent to translucent | Pink<br>Rose red<br>Ruby red |
| **ZIRCON**<br>$ZrSiO_4$<br>**225** | Tetragonal<br>**C**—Prismatic, pyramidal, small, well developed<br>**M**—Irregular lumps, grains | Adamantine<br>Vitreous<br>Resinous<br>Transparent to opaque | Brownish red<br>Dark red |
| **SPINEL,** varieties<br>*Balas*<br>$R''(R'''O_2)_2$ *Ruby*<br>R″ = Mg,Fe, Mn *Rubicelle*<br>R‴ = Al,Fe *Almandine*<br>**267** | Cubic<br>**C**—Octahedral, twins, small<br>**M**—Rounded grains, small pebbles | Vitreous<br>Splendent<br>Transparent to translucent | Deep red<br>Rose red<br>Orange red<br>Bluish red |
| **CORUNDUM,** varieties<br>*Ruby*<br>$Al_2O_3$ *Oriental amethyst*<br>*Common*<br>**228** | Hexagonal<br>**C**—Prismatic, tabular, pyramidal, rhombohedral, rough or rounded barrel-shaped<br>**M**—Compact, granular, lamellar | Vitreous<br>Transparent to translucent | Pink<br>Red<br>Red violet |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 7.<br>7.5 | White | C—None<br>F—Conchoidal, uneven<br>Brittle | 2.9<br>3.2 | Spherical triangular cross-section. Often with zonal distribution of color—red, green, colorless. Frequently as long, divergent, columnar masses imbedded in lepidolite. |
| 7.5 | White | C—Indistinct<br>F—Uneven<br>Brittle | 4.4<br>4.8 | Often in the more acid igneous rocks—granites, syenites; alluvial deposits, with gold, spinel, corundum, garnet. *Hyacinth*, clear and transparent. |
| 8. | White | C—Octahedral, indistinct<br>F—Conchoidal<br>Brittle | 3.5<br>4.1 | *Balas spinel*, rose red; *ruby spinel*, deep red; *rubicelle*, yellow to orange red; *almandine*, bluish red. Usually in precious stone placers, with zircon, garnet, magnetite; more rarely as contact mineral in crystalline limestones. |
| 9. | White | C—None. Nearly rectangular basal and rhombohedral partings, conspicuous; often striated<br>F—Conchoidal<br>Brittle to tough | 3.9<br>4.1 | When massive often multicolored—blue, green, gray. *Ruby*, transparent red; *oriental amethyst*, violet. In limestones, granites; schists, peridotites, alluvial deposits. With magnetite, hematite, nephelite, mica, spinel. |

**Streak—Blue, green, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CHLORITE** (Prochlorite, clinochlorite) $H_8Mg_5Al_2Si_3O_{18}$ ? | Monoclinic<br>**C**—Tabular, six-sided, often bent and twisted<br>**M**—Foliated, scaly, granular, earthy | Pearly<br>Vitreous<br>Dull<br>Translucent to opaque | Grass green<br>Brownish green<br>Blackish green |
| **297** | | | |
| **CHRYSOCOLLA** $H_2CuSiO_4.H_2O$ | Amorphous ?<br>**M**—Compact, reniform, incrustations, seams, stains, earthy | Vitreous<br>Greasy<br>Dull<br>Translucent to opaque | Green<br>Greenish blue<br>Blue |
| **293** | | | |
| **Garnierite** $H_2(Ni,Mg)SiO_4$ | Amorphous ?<br>**M**—Compact, reniform, earthy | Dull<br>Greasy<br>Opaque | Pale green<br>Apple green<br>Emerald green |
| **300** | | | |
| **Chalcanthite** (Blue vitriol) $CuSO_4.5H_2O$ | Triclinic<br>**C**—Tabular, small, rare,<br>**M**—Crusts, reniform, stalactitic, powdery | Vitreous<br>Dull<br>Translucent | Deep blue<br>Sky blue<br>Greenish blue |
| **266** | | | |
| **Brochantite** $CuSO_4.3Cu(OH)_2$ | Orthorhombic<br>**C**—Prismatic, acicular, vertically striated<br>**M**—Reniform, fibrous, drusy crusts | Vitreous<br>Pearly<br>Transparent to translucent | Emerald green<br>Blackish green |
| **263** | | | |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2.5 | Pale green | C—Basal, perfect; when foliated, conspicuous<br>F—Scaly, earthy<br>Tough to brittle | 2.6<br>3. | Laminæ are flexible but inelastic, with slightly soapy feel. Common in schists and serpentine. With magnetite, garnet, diopside, magnesite. Often as a scaly or dusty coating on other minerals. Pseudomorphous after garnet. |
| 2.<br>4. | Pale green<br>Pale blue | F—Conchoidal<br>Brittle | 2.<br>2.2 | Usually recognized by enamel-like appearance, conchoidal fracture, and non-fibrous structure. When impure brownish or blackish. With copper minerals—malachite, azurite, chalcopyrite. |
| 2.<br>3. | Pale green | C—None<br>F—Conchoidal, earthy<br>Brittle | 2.3<br>2.8 | Often as rounded, pea-shaped masses with varnish-like surfaces and earthy interior. Frequently adheres to tongue. With olivine, serpentine, chromite, talc. |
| 2.5 | Light blue | C—Indistinct<br>F—Conchoidal<br>Brittle | 2.1<br>2.3 | Disagreeable metallic taste. Oxidation product of copper sulphide minerals. With chalcopyrite, bornite, melanterite, pyrite. |
| 3.5 | Light green | C—Brachypinacoidal<br>F—Uneven<br>Brittle | 3.8<br>3.9 | Not as common as malachite. Secondary copper mineral. With malachite, azurite, cuprite, chalcopyrite, limonite. |

**Streak—Blue, green, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **AZURITE**<br>$2CuCO_3.Cu(OH)_2$<br>**252** | Monoclinic<br>**C**—Short prismatic, tabular, often in spherical aggregates<br>**M**—Fibrous; botryoidal, with velvety or radial structure; earthy, crusts | Vitreous<br>Dull<br>Translucent to opaque | Azure blue<br>Dark blue |
| **MALACHITE**<br>$CuCO_3.Cu(OH)_2$<br>**252** | Monoclinic<br>**C**—Acicular, often in groups or tufts<br>**M**—Fibrous; stalactitic, botryoidal, with smooth surface and internal banded or radial fibrous structure; velvety crusts, earthy | Silky<br>Adamantine<br>Dull<br>Translucent to opaque | Emerald green<br>Grass green<br>Dark green |
| **PYROMORPHITE**<br>$Pb_5Cl(PO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, thick tabular, rounded and barrel-shaped<br>**M**—Globular, reniform, disseminated, crusts | Greasy<br>Adamantine<br>Translucent to opaque | Dark green<br>Emerald green<br>Yellowish green |
| **Lazurite** (Lapis lazuli)<br>$(Na_2,Ca)_2Al_2[Al(NaSO_4, NaS_3,Cl)](SiO_4)_3$<br>**303** | Cubic<br>**C**—Dodecahedrons, rare<br>**M**—Compact, irregular grains | Vitreous<br>Translucent to opaque | Azure blue<br>Violet blue<br>Greenish blue |
| **HORNBLENDE** (Amphibole)<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**312** | Monoclinic<br>**C**—Long prismatic, prism angle 124°; often with rhombohedral-like terminations<br>**M**—Bladed, fibrous, granular, compact | Vitreous<br>Silky<br>Translucent to opaque | Blackish green<br>Dark green |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.5**<br>**4.** | Blue | **C**—Domatic<br>**F**—Conchoidal<br>Brittle | 3.7<br>3.8 | Common alteration product of copper minerals. With malachite, cuprite, native copper, chalcocite, chalcopyrite, bornite. Pseudomorphous after cuprite, tetrahedrite. Alters to malachite. |
| **3.5**<br>**4.** | Light green | **C**—Basal, pinacoidal<br>**F**—Conchoidal, splintery<br>Brittle | 3.7<br>4.1 | Very common alteration product of copper minerals. With azurite, cuprite, native copper, chalcocite, chalcopyrite, bornite. Pseudomorphous after cuprite, azurite, native copper. Surface may be almost black, due to the oxide, melaconite. |
| **3.5**<br>**4.** | Yellow<br>Greenish yellow | **C**—None<br>**F**—Conchoidal, uneven<br>Brittle | 6.5<br>7.1 | Alteration product of lead minerals. With galena, cerussite, barite, limonite. |
| **5.**<br>**5.5** | Pale blue | **C**—Dodecahedral, distinct<br>**F**—Uneven<br>Brittle | 2.4 | Always blue and contains disseminated pyrite. Occurs as contact mineral in crystalline limestone. |
| **5.**<br>**6.** | Grayish green<br>Grayish brown<br>Yellowish | **C**—Prismatic, perfect, often conspicuous—124°<br>Brittle | 2.9<br>3.3 | Simple, pseudohexagonal crystals, and cleavage—124°—important. In nearly all types of igneous rocks. With quartz, feldspar, pyroxene, chlorite, calcite. |

**Streak—Blue, green, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **AUGITE** (Pyroxene)<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**307** | Monoclinic<br>**C**—Short, prismatic, thick columnar; prism angle 87°<br>**M**—Compact, granular, disseminated | Vitreous<br>Submetallic<br>Translucent to opaque | Blackish green<br>Leek green |
| **Turquois**<br>$Al_2(OH)_3PO_4.H_2O$<br>**276** | Triclinic ?<br>**C**—Small, rare<br>**M**—Reniform, stalactitic, disseminated, rounded pebbles | Waxy<br>Dull<br>Opaque to translucent | Sky blue<br>Bluish green<br>Apple green |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **Asbestos,** variety *Chrysotile*<br>$H_4Mg_3Si_2O_9$<br>**298** | Orthorhombic ?<br>**M**—Fibrous, coarse or fine; felted | Silky<br>Silky metallic<br>Opaque | Light green<br>Olive green |
| variety *Amphibole*<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**311** | Monoclinic ?<br>**M**—Fibrous, coarse or fine; felted | Silky<br>Opaque | Greenish |
| **TALC,** varieties *Foliated* *Soapstone* or *steatite*<br>$H_2Mg_3Si_4O_{12}$<br>**299** | Monoclinic<br>**C**—Thin tabular, indistinct<br>**M**—Foliated, globular, granular, compact, fibrous | Pearly<br>Greasy<br>Opaque to transparent | Pale green<br>Apple green<br>Dark green |

**Hardness 1 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.**<br>**6.** | Pale green<br>Grayish green | C—Prismatic, perfect, conspicuous—87°<br>Brittle | 3.2<br>3.6 | Crystals, usually eight sided, more rarely four-sided; pseudotetragonal with prism angles of 87° and 93°. Cleavage less distinct than on hornblende. Common in basic eruptive rocks and crystalline limestones. |
| **6.** | Pale green | F—Conchoidal<br>Brittle | 2.6<br>2.8 | Secondary mineral, common in thin veins, crusts, or coatings. With limonite, quartz, feldspar, kaolin. |

**Hardness 1 to 3**

| | | | | |
|---|---|---|---|---|
| **1.**<br>**2.5** | White | F—Fibrous<br>Flexible | 1.<br>2.5 | Delicate, fine, parallel-flexible fibers perpendicular to walls, easily separable, called *short fibered asbestos;* compare below. In veins or seams in compact serpentine. |
| **1.**<br>**2.5** | White | F—Fibrous<br>Flexible | 1.<br>2.5 | *Long fibered asbestos*, parallel, flexible fibers. Fibers parallel to walls. Compare above. |
| **1.**<br>**2.5** | White | C—Basal, conspicuous on foliated masses<br>F—Uneven<br>Sectile, laminæ flexible | 2.6<br>2.8 | Greasy or soapy feel. *Foliated*, easily separable, inelastic folia or plates, H = 1; *Soapstone* or *steatite*, coarse to fine granular, more or less impure, H = 1.5 – 2.5. With serpentine, dolomite, magnesite, actinolite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CHLORITE** (Prochlorite, clinochlorite)<br>$H_8Mg_5Al_2Si_3O_{18}$ ?<br>**297** | Monoclinic<br>**C**—Tabular, six-sided, often bent, twisted<br>**M**—Foliated, scaly, granular, earthy | Pearly<br>Vitreous<br>Dull<br>Translucent to opaque | Grass green<br>Brownish green<br>Blackish green |
| **Melanterite** (Copperas)<br>$FeSO_4.7H_2O$<br>**266** | Monoclinic<br>**C**—Rare<br>**M**—Capillary, fibrous, stalactitic, concretionary, powder | Vitreous<br>Dull<br>Transparent to translucent | Green<br>Yellowish green |
| **CHRYSOCOLLA**<br>$H_2CuSiO_4.H_2O$<br>**293** | Amorphous ?<br>**M**—Compact, reniform, incrustations, seams, stains, earthy | Vitreous<br>Greasy<br>Dull<br>Translucent to opaque | Green<br>Greenish blue<br>Blue |
| **Garnierite**<br>$H_2(Ni,Mg)SiO_4$<br>**300** | Amorphous ?<br>**M**—Compact, reniform, earthy | Dull<br>Greasy<br>Opaque | Pale green<br>Apple green<br>Emerald green |
| **Actinolite** (Amphibole)<br>$Ca(Mg, Fe)_3(SiO_3)_4$<br>**311** | Monoclinic<br>**C**—Fine, acicular<br>**M**—Interwoven fibrous aggregates, radiating masses | Vitreous<br>Silky<br>Translucent to opaque | Grass green<br>Grayish green |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2.5 | White<br>Greenish white | C—Basal, conspicuous, when foliated<br>F—Scaly, earthy<br>Tough to brittle | 2.6<br>3. | Laminæ flexible but inelastic, with slightly soapy feel. Common in schists and serpentine. With magnetite, magnesite, garnet, diopside. Often as scaly or dusty coating on other minerals. Pseudomorphous after garnet. |
| 2. | White | C—Basal, not conspicuous<br>F—Conchoidal, earthy<br>Brittle | 1.8<br>1.9 | On exposure loses water and crumbles to powder. Sweet, astringent taste, somewhat metallic. Oxidation product of iron sulphide minerals—marcasite, pyrite, chalcopyrite, pyrrhotite. |
| 2.<br>3. | White<br>Greenish white<br>Bluish white | F—Conchoidal<br>Brittle | 2.<br>2.2 | Usually recognized by enamel-like appearance, conchoidal fracture, and no fibrous structure. When impure brownish or blackish. With copper minerals—malachite, azurite, chalcopyrite; also limonite. |
| 2.<br>3. | White<br>Greenish white | C—None<br>F—Conchoidal, earthy<br>Brittle | 2.3<br>2.8 | Often as rounded, pea-shaped masses, with varnish-like surfaces and earthy interior. May adhere to tongue. With olivine, serpentine, chromite, talc. |
| 2.<br>3. | White<br>Greenish white | C—Fibrous<br>Brittle | 2.9<br>3.2 | Masses of delicate, interwoven fibers—*actinolite schist.* A pale grayish green, highly ferruginous variety (*grünerite*, $Fe_4(SiO_3)_4$) associated with quartz and magnetite is termed *magnetite-grünerite schist.* |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Chalcanthite** (Blue vitriol)<br>$CuSO_4.5H_2O$<br>**266** | Triclinic<br>**C**—Tabular, small, rare<br>**M**—Crusts, reniform, stalactitic, fibrous, powdery | Vitreous<br>Dull<br>Translucent | Deep blue<br>Sky blue<br>Greenish blue |
| **BIOTITE** (Mica)<br>$(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$<br>**294** | Monoclinic<br>**C**—Tabular, hexagonal or rhombohedral habit<br>**M**—Plates, disseminated scales | Pearly<br>Submetallic<br>Transparent to opaque | Brownish green<br>Blackish green |
| **BARITE** (Heavy spar)<br>$BaSO_4$<br>**256** | Orthorhombic<br>**C**—Tabular, prismatic, crested divergent groups, common<br>**M**—Compact, lamellar, fibrous, cleavable, reniform | Vitreous<br>Pearly<br>Transparent to opaque | Bluish<br>Greenish |
| **CALCITE**<br>$CaCO_3$<br>**242** | Hexagonal<br>**M**—Cleavable, granular, fibrous, compact | Vitreous<br>Dull<br>Transparent to nearly opaque | Sky blue<br>Deep blue<br>Greenish |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **ANHYDRITE**<br>$CaSO_4$<br>**254** | Orthorhombic<br>**C**—Thick tabular, prismatic, rare<br>**M**—Granular, compact, fibrous, lamellar, cleavable, reniform | Vitreous<br>Pearly<br>Translucent to opaque | Bluish<br>Grayish blue<br>Blue |

### Hardness 1 to 3

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 2.5 | White<br>Bluish white | C—Indistinct<br>F—Conchoidal, earthy<br>Brittle | 2.1<br>2.3 | Disagreeable metallic taste. Oxidation product of copper sulphide minerals. With chalcopyrite, bornite, melanterite, pyrite. |
| 2.5<br>3. | White<br>Grayish | C—Basal, perfect, conspicuous<br>Tough, laminæ of fresh biotite very elastic | 2.7<br>3.2 | Easily recognized by structure, highly perfect cleavage, and elasticity. Important constituent of many igneous and metamorphic rocks—granite, syenite, gneiss. |
| 2.5<br>3. | White | C—Basal, prismatic, conspicuous<br>F—Uneven<br>Brittle | 4.3<br>4.7 | Characterized by rather high specific gravity and cleavages. In metalliferous veins; pockets, lenticular masses in limestone. With galena, sphalerite, chlorite, chalcopyrite; manganese and iron minerals. |
| 3. | White | C—Rhombohedral perfect, conspicuous<br>F—Conchoidal<br>Brittle | 2.7 | Rhombohedral cleavage generally characteristic. Cleavages often show striations. |

### Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.<br>3.5 | White | C—Pinacoidal, perfect, 3 directions at 90°<br>F—Conchoidal<br>Brittle | 2.8<br>3. | Pseudocubical cleavage, sometimes noted. Granular varieties resemble marble. Not as heavy as celestite or barite. In limestone, shale. With halite, gypsum. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CELESTITE**<br>$SrSO_4$<br>**255** | Orthorhombic<br>**C**—Tabular, prismatic, common; pyramidal<br>**M**—Compact, cleavable, fibrous, granular, reniform | Vitreous<br>Pearly<br>Transparent to translucent | Sky blue<br>Blue<br>Greenish |
| **BARITE** (Heavy spar)<br>$BaSO_4$<br>**256** | Orthorhombic<br>**C**—Tabular, prismatic, crested divergent groups, common<br>**M**—Compact, lamellar, fibrous, cleavable, reniform | Vitreous<br>Pearly<br>Transparent to translucent | Bluish<br>Greenish |
| **CHRYSOCOLLA**<br>$H_2CuSiO_4.H_2O$<br>**293** | Amorphous ?<br>**M**—Compact, reniform, incrustations, seams, stains, earthy | Vitreous<br>Greasy<br>Dull<br>Translucent to opaque | Blue<br>Bluish green<br>Green |
| **SERPENTINE**<br>$H_4Mg_3Si_2O_9$<br>**297** | Orthorhombic ?<br>**C**—Unknown<br>**M**—Compact, columnar, fibrous, lamellar, granular | Greasy<br>Waxy<br>Translucent to opaque | Light green<br>Olive green<br>Yellowish green<br>Blackish green |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.**<br>**3.5** | White | C—Basal, prismatic, conspicuous<br>F—Uneven<br>Brittle | 3.9<br>4. | Heavier than calcite, anhydrite; lighter than barite. In limestones, dolomites, shales. With sulphur, gypsum, aragonite, halite, galena, sphalerite. |
| **3.**<br>**3.5** | White | C—Basal, prismatic, conspicuous<br>F—Uneven<br>Brittle | 4.3<br>4.7 | Characterized by rather high specific gravity and cleavages. In metalliferous veins; pockets, lenticular masses in limestone. With galena, sphalerite, chalcopyrite; manganese and iron minerals. |
| **3.**<br>**4.** | White<br>Greenish white<br>Bluish white | F—Conchoidal<br>Brittle | 2.<br>2.2 | Usually recognized by enamel-like appearance, conchoidal fracture, and non-fibrous structure. When impure brownish or blackish. With copper minerals—malachite, azurite, chalcopyrite; also limonite. |
| **3.**<br>**4.** | White | F—Conchoidal, splintery<br>Brittle | 2.5<br>2.8 | Smooth and greasy feel. Often spotted, clouded, and multi-colored. Sometimes crossed by seams of asbestos (chrysotile). *Verd-antique*, massive, green and mixed with calcite, dolomite, or magnesite; takes an excellent polish. With magnesite, chromite, garnierite, pyrope, platinum. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Wavellite**<br>$(Al.OH)_3(PO_4)_2.5H_2O$<br>**276** | Orthorhombic<br>**C**—Capillary, small<br>**M**—Crusts, globular or hemispherical, with radial fibrous structure | Vitreous<br>Translucent | Green<br>Bluish green<br>Blue |
| **PYROMORPHITE**<br>$Pb_5Cl(PO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, thick tabular, rounded and barrel-shaped; acicular<br>**M**—Globular, reniform, disseminated, crusts | Greasy<br>Adamantine<br>Translucent to opaque | Dark green<br>Emerald green<br>Yellowish green |
| **FLUORITE** (Fluor spar)<br>$CaF_2$<br>**239** | Cubic<br>**C**—Cubes, alone or modified, well developed, common; penetration twins<br>**M**—Cleavable, granular, fibrous | Vitreous<br>Transparent to nearly opaque | Greenish<br>Bluish green<br>Blue violet |
| **CYANITE** (Disthene, kyanite)<br>$Al_2SiO_5$<br>**282** | Triclinic<br>**C**—Long, bladed, without good terminations; sometimes curved and radially grouped<br>**M**—Coarsely bladed, columnar, fibrous | Vitreous<br>Translucent to transparent | Sky blue<br>Greenish blue<br>Bluish white |
| **APATITE**<br>$Ca_5F(PO_4)_3$<br>**273** | Hexagonal<br>**C**—Prismatic, thick, tabular, common, sometimes large with rounded edges<br>**M**—Compact, fibrous, nodular, reniform | Greasy<br>Vitreous<br>Translucent to opaque | Grass green<br>Brownish green<br>Bluish green<br>Blue violet |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.5<br>4. | White | C—Pinacoidal, domatic<br>F—Conchoidal, uneven, fibrous<br>Brittle | 2.3<br>2.4 | Secondary mineral occurring on surfaces of rocks or minerals, as crystalline crusts with pronounced radial, fibrous structure. |
| 3.5<br>4. | White<br>Yellowish white | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.5<br>7.1 | Common alteration product of lead minerals. With galena, cerussite, barite, limonite. |
| 4. | White | C—Octahedral, perfect, conspicuous<br>Brittle | 3.<br>3.2 | May show fluorescence. Easily recognized by crystal form, octahedral cleavage, and hardness. Common gangue of metallic ores—galena, sphalerite, cassiterite; also with calcite, barite. |
| 4.<br>5. | White | C—Pinacoidal, perfect, conspicuous<br>Brittle | 3.5<br>3.7 | Color irregularly distributed, frequently with lighter longitudinal margins. Hardness varies with direction, 4–5 parallel to long direction, 6–7 at right angles thereto. In gneiss, mica schist. With staurolite, garnet, corundum. |
| 4.5<br>5. | White | C—Basal, imperfect<br>F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | Crystals may be vertically striated and have fused appearance. Color often unevenly distributed—brownish spots. In crystalline limestones; metalliferous ore deposits; igneous rocks. With quartz, cassiterite, fluorite, wolframite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **SMITHSONITE**<br>$ZnCO_3$<br>**247** | Hexagonal<br>**C**—Small, usually as druses or crusts<br>**M**—Botryoidal, stalactitic, granular, fibrous, compact | Vitreous<br>Dull<br>Translucent | Green<br>Grayish green<br>Greenish blue<br>Blue |
| **Lazurite** (Lapis lazuli)<br>$(Na_2,Ca)_2Al_2[Al(NaSO_4, NaS_3,Cl)](SiO_4)_3$<br>**303** | Cubic<br>**C**—Dodecahedrons, rare<br>**M**—Compact, irregular grains | Vitreous<br>Translucent to opaque | Azure blue<br>Violet blue<br>Greenish blue |
| **Datolite**<br>$Ca(B.OH)SiO_4$<br>**283** | Monoclinic<br>**C**—Prismatic, pyramidal, tabular, highly modified<br>**M**—Compact, fibrous, granular, botryoidal | Vitreous<br>Greasy<br>Dull<br>Transparent to opaque | Pale green<br>Olive green |
| **TITANITE** (Sphene)<br>$CaTiSiO_5$<br>**323** | Monoclinic<br>**C**—Wedge- or envelope-shaped when disseminated; tabular or prismatic when attached<br>**M**—Compact, lamellar | Vitreous<br>Greasy<br>Transparent to translucent | Green<br>Yellowish green |
| **Sodalite**<br>$Na_4Al_2(AlCl)(SiO_4)_3$<br>**303** | Cubic<br>**C**—Dodecahedrons<br>**M**—Compact, disseminated grains, nodular | Vitreous<br>Greasy<br>Transparent to translucent | Lavender blue<br>Sky blue<br>Dark blue<br>Greenish |
| **NEPHELITE** (Nepheline, elæolite)<br>$(Na,K)_3Al_3Si_9O_{34}$<br>**301** | Hexagonal<br>**C**—Short prismatic, tabular<br>**M**—Compact, disseminated grains | Greasy<br>Vitreous<br>Transparent to opaque | Grayish green<br>Brownish green<br>Grayish blue |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.** | White<br>Gray | C—Rhombohedral, not often observed<br>F—Uneven, splintery<br>Brittle | 4.1<br>4.5 | With zinc minerals, especially sphalerite, hemimorphite. |
| **5.**<br>**5.5** | White<br>Bluish white | C—Dodecahedral, imperfect<br>F—Uneven<br>Brittle | 2.4 | Always blue and contains disseminated pyrite. Occurs as contact mineral in crystalline limestone. |
| **5.**<br>**5.5** | White | C—None<br>F—Conchoidal, uneven<br>Brittle | 2.9<br>3. | Crystals glassy and usually well developed. Compact masses often with brownish, yellowish, reddish streaks and spots. In cracks and cavities in basic igneous rocks. With calcite, native copper, magnetite, zeolites. |
| **5.**<br>**5.5** | White<br>Grayish | C—Prismatic, conspicuous parting often noted<br>F—Conchoidal<br>Brittle | 3.4<br>3.6 | With feldspars, pyroxenes, amphiboles, chlorite, scapolite, zircon. |
| **5.**<br>**6.** | White | C—Dodecahedral<br>F—Conchoidal, uneven<br>Brittle | 2.2<br>2.4 | Commonly massive and blue in color. Recognized by associates—nephelite, cancrinite, leucite, feldspar, zircon; not with quartz. |
| **5.**<br>**6.** | White | C—Indistinct<br>F—Conchoidal, uneven<br>Brittle | 2.6 | Greasy luster and associates important. With feldspar, cancrinite, biotite, sodalite, zircon, leucite; not with quartz. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **SCAPOLITE** (Wernerite)<br>$\left\{ \begin{matrix} n\mathrm{Na_4Al_3Si_9O_{24}Cl} \\ m\mathrm{Ca_4Al_6Si_6O_{25}} \end{matrix} \right.$<br>**322** | Tetragonal<br>**C**—Thick prismatic, coarse, often large<br>**M**—Compact, granular, fibrous, columnar | Vitreous<br>Greasy<br>Translucent to opaque | Grayish green<br>Bluish |
| **AMPHIBOLES** | | | |
| Actinolite<br>$\mathrm{Ca(Mg,Fe)_3(SiO_3)_4}$<br>**310** | Monoclinic<br>**C**—Bladed, without terminations<br>**M**—Columnar, fibrous, often divergent; granular, compact | Vitreous<br>Silky<br>Transparent to opaque | Light green<br>Grayish green<br>Dark green |
| **HORNBLENDE**<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**312** | Monoclinic<br>**C**—Long prismatic, prism angle 124°; often with rhombohedral-like terminations<br>**M**—Bladed, fibrous, granular, compact | Vitreous<br>Silky<br>Translucent to opaque | Blackish green<br>Dark green |
| **PYROXENES** | | | |
| **BRONZITE**<br>$\mathrm{(Mg,Fe)_2(SiO_3)_2}$<br>**304** | Orthorhombic<br>**C**—Prismatic, rare<br>**M**—Fibrous, lamellar, compact | Bronzy<br>Silky<br>Translucent to opaque | Grayish green<br>Brownish green<br>Olive green |
| **DIOPSIDE**<br>$\mathrm{CaMg(SiO_3)_2}$<br>**305** | Monoclinic<br>**C**—Prismatic, thick columnar, prism angle 87°<br>**M**—Compact, granular, columnar, lamellar | Vitreous<br>Dull<br>Transparent to opaque | Pale green<br>Bright green<br>Dark green |

(See also Augite on next page).

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>6. | White | C—Prismatic<br>F—Conchoidal<br>Brittle | 2.6<br>2.8 | Crystals may appear as though fused. Typical contact mineral. In metamorphic rocks, especially granular limestones. With pyroxenes, garnet, mica, amphiboles, wollastonite. |
| 5.<br>6. | White<br>Greenish white | C—Prismatic, often conspicuous, 124°<br>Brittle | 2.9<br>3.2 | Often as radiating masses. In talc and chlorite schists. With serpentine, epidote, calcite. *Nephrite* and *jade* are compact massive varieties. |
| 5.<br>6. | Gray<br>Greenish gray<br>Brownish gray | C—Prismatic, often conspicuous, 124°<br>Brittle | 2.9<br>3.3 | Simple, pseudohexagonal crystals, and cleavage—124°—important. Common in many types of rocks. With quartz, feldspar, pyroxene, chlorite, calcite. |
| 5.<br>6. | White<br>Grayish | C—Prismatic, pinacoidal, often conspicuous<br>F—Uneven<br>Brittle | 3.2<br>3.5 | Cleavage surfaces often fibrous or lamellar, irregular or wavy, with distinct bronzy luster. In basic igneous rocks. |
| 5.<br>6. | White<br>Gray | C—Prismatic; conspicuous basal parting<br>F—Uneven<br>Brittle | 3.2<br>3.3 | Crystals prismatic and pseudotetragonal with distinct basal parting. May have colorless and dark green zones. In crystalline limestones and schists. With vesuvianite, garnet, scapolite, spinel, apatite. |

**Streak—Uncolored, white, or light gray**

| | Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|---|
| PYROXENE | **AUGITE**<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**307** | Monoclinic<br>**C**—Short prismatic, thick columnar, prism angle 87°<br>**M**—Compact, granular, disseminated | Vitreous<br>Submetallic<br>Translucent to opaque | Blackish green<br>Leek green |
| | **Willemite**<br>$Zn_2SiO_4$<br>**289** | Hexagonal<br>**C**—Prismatic<br>**M**—Compact, granular, disseminated grains | Vitreous<br>Greasy<br>Translucent to opaque | Apple green<br>Yellowish green |
| | **OPAL**<br>$SiO_2.xH_2O$<br>**232** | Amorphous<br>**M**—Reniform, botryoidal, compact | Vitreous<br>Greasy<br>Translucent to opaque | Green<br>Bluish green<br>Blue |
| | **Turquois**<br>$Al_2(OH)_3PO_4.H_2O$<br>**276** | Triclinic<br>**M**—Reniform, stalactitic, disseminated grains, rounded pebbles | Waxy<br>Dull<br>Opaque to translucent | Sky blue<br>Bluish green<br>Apple green |

**Streak—Uncolored, white, or light gray**

| | | | | |
|---|---|---|---|---|
| FELDSPARS | **MICROCLINE**, variety *Amazonstone*<br>$KAlSi_3O_8$<br>**318** | Triclinic<br>**C**—Prismatic, thick tabular, twins<br>**M**—Cleavable, granular, compact, disseminated | Vitreous<br>Pearly<br>Translucent to transparent | Bright green<br>Bluish green |
| | **LABRADORITE**<br>Silicate of Ca, Na, Al<br>**321** | Triclinic<br>**C**—Thin tabular, often with rhombic cross-section<br>**M**—Compact, cleavable, granular | Vitreous<br>Pearly<br>Translucent to nearly opaque | Grayish green<br>Greenish |

### Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>6. | White<br>Gray<br>Greenish gray | C—Prismatic, perfect, conspicuous—87°, (less distinct than on hornblende.)<br>Brittle | 3.2<br>3.6 | Crystals usually eight-sided, more rarely four-sided; pseudotetragonal with prism angles of 87° and 93°. In basic rocks and limestones. |
| 5.<br>6. | White | C—Basal<br>F—Uneven<br>Brittle | 3.9<br>4.3 | Characterized by associates—franklinite (black), zincite (red), rhodonite (flesh red), calcite. |
| 5.5<br>6. | White | F—Conchoidal, conspicuous | 2.1<br>2.3 | Structure and fracture characteristic. *Precious opal*, play of colors. In veins, cavities, and masses of irregular outline. |
| 6. | White<br>Greenish white | F—Conchoidal<br>Brittle | 2.6<br>2.8 | Secondary mineral, in thin veins, crusts, or coatings. With quartz, feldspar, kaolin, limonite. |

### Hardness over 6

| | | | | |
|---|---|---|---|---|
| 6.<br>6.5 | White | C—Basal, brachypinacoidal, conspicuous, 90° 30′<br>F—Uneven<br>Brittle | 2.5<br>2.6 | Slightly inclined cleavages; may show twinning striations on basal pinacoid. With quartz, other feldspars, mica, hornblende, topaz. |
| 6<br>6.5 | White | C—Basal, brachypinacoidal, conspicuous, 86°<br>F—Uneven, conchoidal<br>Brittle | 2.7 | Often with play of color—yellow, green, blue, red. Inclined cleavages are striated. In basic igneous rocks. With pyroxenes, amphiboles. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **EPIDOTE**<br>$Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$<br>**286** | Monoclinic<br>**C**—Prismatic, elongated and deeply striated parallel to *b* axis; usually terminated on one end only<br>**M**—Columnar, fibrous, parallel and divergent; granular | Vitreous<br>Transparent to opaque | Blackish green<br>Yellowish green<br>Brownish green<br>Pea green |
| **CYANITE** (Disthene, kyanite)<br>$Al_2SiO_5$<br>**282** | Triclinic<br>**C**—Long bladed, without good terminations; sometimes curved and radially grouped<br>**M**—Coarsely bladed, columnar, fibrous | Vitreous<br>Translucent to transparent | Sky blue<br>Greenish blue<br>Bluish white |
| **VESUVIANITE**<br>$Ca_6[Al(OH,F)]Al_2(SiO_4)_5$<br>**288** | Tetragonal<br>**C**—Short prismatic<br>**M**—Compact, granular, aggregates with parallel or divergent striations | Vitreous<br>Greasy<br>Translucent to opaque | Green<br>Brownish green<br>Bluish |
| **OLIVINE** (Chrysolite, peridot)<br>$(Mg,Fe)_2SiO_4$<br>**289** | Orthorhombic<br>**C**—Prismatic, thick tabular<br>**M**—Rounded, disseminated glassy grains; granular aggregates | Vitreous<br>Transparent to translucent | Grass green<br>Olive green<br>Yellowish green |
| **GARNET,** varieties<br>*Grossularite*<br>$R_2'''R_3''$ *Uvarovite*<br>$(SiO_4)_3$ *Andradite*<br>R''' = Al,Fe,Cr<br>R'' = Ca,Fe,Mg<br>**290** | Cubic<br>**C**—Dodecahedrons, tetragonal trisoctahedrons, alone or in combination<br>**M**—Granular, compact, lamellar, disseminated grains, sand | Vitreous<br>Transparent to opaque | Pale green<br>Grass green<br>Emerald green |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>7. | White<br>Grayish | C—Basal<br>F—Uneven<br>Brittle | 3.3<br>3.5 | Crystals are often dark or blackish green, massive aggregates lighter colored. With quartz, feldspar, garnet, hornblende, pyroxene, magnetite, native copper, zeolites. |
| 6.<br>7. | White | C—Pinacoidal, perfect, conspicuous<br>Brittle | 3.5<br>3.7 | Color irregularly distributed, frequently with lighter longitudinal margins. Hardness varies with direction, 4–5 parallel to long direction, 6–7 at right angles thereto. In gneiss, mica schist. With staurolite, corundum. |
| 6.5 | White | C—Basal, prismatic, indistinct<br>F—Uneven<br>Brittle | 3.3<br>3.5 | In crystalline limestone, gneiss, schists. With garnet, tourmaline, chondrodite, wollastonite, epidote, pyroxene. |
| 6.5<br>7. | White<br>Yellowish white | C—Pinacoidal<br>F—Conchoidal<br>Brittle | 3.2<br>3.6 | In basic rocks—basalts, traps; crystalline, limestones. With augite, magnetite, spinel, plagioclase, chromite, pyrope. |
| 6.5<br>7.5 | White | C—Dodecahedral, usually indistinct<br>F—Conchoidal, uneven<br>Brittle | 3.4<br>4.3 | *Grossularite*, in crystalline limestones and dolomites, with wollastonite, vesuvianite, diopside, scapolite; *uvarovite*, in serpentine, with chromite, or in crystalline limestones; *andradite*, with feldspar, nephelite, leucite, epidote, magnetite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **QUARTZ,** Phanerocrystalline varieties | Hexagonal | Vitreous | Green |
| | **C**—Prismatic, horizontally striated | Greasy | Greenish blue |
| $SiO_2$ | | Transparent to opaque | Blue |
| *Cat's eye* | **M**—Compact, granular | | Blue violet |
| *Amethyst* | | | |
| **222** | | | |
| Cryptocrystalline varieties | Hexagonal | Waxy | Light green |
| | **C**—Never in crystals | Vitreous | Dark green |
| *Chalcedony* | **M**—Nodular, spotted, concretionary, stalactitic, compact | Translucent to opaque | Grayish blue |
| *Chrysoprase* | | | Greenish blue |
| *Heliotrope* | | | |
| **223** | | | |
| **TOURMALINE** | Hexagonal | Vitreous | Green |
| | **C**—Prismatic, vertically striated; terminated with broken or rhombohedral-like surfaces | Transparent to translucent | Blue |
| $M_9'Al_3(B.OH)_2Si_4O_{19}$ | | | |
| $M' = Na,K,Li,Mg,Fe$ | **M**—Compact, columnar | | |
| **284** | | | |
| **BERYL,** varieties | Hexagonal | Vitreous | Pale green |
| *Emerald* | **C**—Long prismatic, often vertically striated, large | Transparent to translucent | Emerald green |
| $Be_3Al_2(SiO_3)_6$ *Aquamarine* | | | Bluish green |
| *Common* | **M**—Columnar, granular, compact, rounded pebbles | | Sky blue |
| **313** | | | |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **7.** | White | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle | 2.6 | Characteristic conchoidal fracture and glassy luster. *Chloritic quartz*, green from included chlorite; *cat's eye*, opalescent, due to included fibers of asbestos; *amethyst*, purple or blue violet, usually in crystals. |
| **7.** | White | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle to tough | 2.6 | Not as glassy as phanerocrystalline varieties. *Chalcedony*, *chrysoprase*, *prase*, *plasma*, uniform in color; *heliotrope*, spotted. To distinguish, see reference. |
| **7.**<br>**7.5** | White | C—None<br>F—Conchoidal, uneven<br>Brittle | 2.9<br>3.2 | Spherical triangular cross-section. With zonal distribution of color—green, red, colorless. In igneous and metamorphic rocks. With lepidolite, feldspar, quartz, biotite. |
| **7.5**<br>**8.** | White | C—Indistinct<br>F—Conchoidal, uneven<br>Brittle | 2.6<br>2.8 | Crystals usually simple—prism and base. *Emerald*, transparent and emerald green; *aquamarine*, transparent, bluish to sea green or yellowish green. In granitic rocks, mica schists, clay slates, placers. With quartz, feldspar, mica, topaz, tourmaline, cassiterite, chrysoberyl, garnet. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **SPINEL,** varieties<br>$R''(R'''O_2)_2$ *Pleonaste*<br>R'' = Mg,Fe *Gahnite*<br>Zn,Mn *Blue spinel*<br>R''' = Al,Fe | Cubic<br>**C**—Octahedral, usually well developed<br>**M**—Compact, granular, disseminated grains | Vitreous<br>Dull<br>Translucent to opaque | Grass green<br>Dark green<br>Grayish green<br>Light blue |
| **267** | | | |
| **Chrysoberyl,** varieties<br>*Ordinary*<br>Be- *Alexandrite*<br>$(AlO_2)_2$ *Cat's eye* | Orthorhombic<br>**C**—Tabular; heart-shaped, pseudohexagonal twins<br>**M**—Compact; loose, rounded grains | Vitreous<br>Greasy<br>Transparent to translucent | Light green<br>Yellowish green<br>Emerald green |
| **271** | | | |
| **CORUNDUM,** varieties<br>*Sapphire*<br>$Al_2O_3$ *Oriental emerald*<br>*Oriental amethyst*<br>*Common* | Hexagonal<br>**C**—Prismatic, tabular, pyramidal, rhombohedral; rough or rounded barrel-shaped<br>**M**—Compact, granular, lamellar | Vitreous<br>Transparent to opaque | Green<br>Blue<br>Blue violet |
| **228** | | | |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **7.5**<br>**8.** | White<br>Grayish | C—Octahedral, indistinct<br>F—Conchoidal<br>Brittle | 3.5<br>4.4 | Commonly as contact mineral in granular limestones; in more basic igneous rocks; rounded grains in placers. With calcite, chondrodite, serpentine, corundum, graphite, pyroxenes. |
| **8.5** | White | C—Brachypinacoidal<br>F—Uneven, conchoidal<br>Brittle | 3.6<br>3.8 | Crystals disseminated as plates with feather-like or radial striations. *Alexandrite*, red in transmitted light; *cat's eye*, opalescent. In mica schist, gneiss; granite; also in placers. With beryl, garnet, tourmaline, sillimanite. |
| **9.** | White | C—None; nearly rectangular basal and rhombohedral partings, conspicuous; often striated<br>F—Conchoidal<br>Brittle to tough | 3.9<br>4.1 | When massive, often multi-colored—red, gray, yellow. *Sapphire*, transparent, blue; *oriental emerald*, green, transparent; *oriental amethyst*, violet. In limestone, granite, syenite, schist, peridotite; placers. With magnetite, nephelite, mica, chlorite, spinel. |

**Streak—Red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Carnotite**<br>$K_2O.2U_2O_3.V_2O_5.3H_2O$?<br>**277** | Orthorhombic<br>**C**—Tabular, small rhombic plates<br>**M**—Scaly aggregates, incrustations, crystalline powder | Resinous<br>Vitreous<br>Dull<br>Transparent to translucent | Canary yellow<br>Greenish yellow |
| **BAUXITE**<br>$Al_2O(OH)_4$<br>**235** | Never in crystals<br>**M**—Pisolitic, oolitic, round disseminated grains, clay-like, earthy | Dull<br>Earthy<br>Opaque | Yellow<br>Yellowish brown<br>Brown |
| **LIMONITE**, varieties<br>*Yellow ocher*<br>*Brown ocher*<br>*Bog iron ore*<br>*Brown clay ironstone*<br>$Fe_2O_3.H_2O$<br>**235** | **M**—Earthy, porous, clay-like, oolitic, pisolitic | Earthy<br>Dull<br>Opaque | Yellow<br>Yellowish brown<br>Dark brown |
| **ORPIMENT**<br>$As_2S_3$<br>**204** | Monoclinic<br>**C**—Rare<br>**M**—Foliated, granular, reniform, fibrous, crusts | Greasy<br>Pearly<br>Translucent | Lemon yellow |
| **REALGAR**<br>AsS<br>**203** | Monoclinic<br>**C**—Short prismatic, rare<br>**M**—Compact, granular, incrustations | Resinous<br>Transparent to translucent | Reddish yellow<br>Orange yellow |
| **SULPHUR**<br>S<br>**193** | Orthorhombic<br>**C**—Pyramidal, tabular<br>**M**—Granular, fibrous, earthy, crusts, compact | Greasy<br>Adamantine<br>Translucent | Straw yellow<br>Honey yellow<br>Brownish yellow<br>Reddish yellow |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2. | Yellow | C—Basal, perfect<br>F—Earthy<br>Brittle | | Occurs as a powder or in loosely cohering masses, intimately mixed with sand and sandstones. With malachite, azurite, biotite, magnetite. |
| 1.<br>3. | Yellow<br>Brown | F—Earthy<br>Brittle | 2.5<br>2.6 | Color and streak variable, due to pigments. Clay odor, when breathed upon. Commonly with pisolitic or oolitic structure. With clay or kaolinite, in nodules, grains, or irregular masses in limestone or dolomite. |
| 1.<br>3. | Yellowish brown<br>Dark brown | F—Earthy | 3.4<br>4. | *Yellow ocher*, earthy, and yellow, when impure gritty; *brown ocher*, earthy and brown; *bog iron ore*, porous; *brown clay ironstone*, massive or concretionary, impure from clay, sand. Ocherous varieties may soil fingers. |
| 1.5<br>2. | Lemon yellow | C—Clinopinacoidal, usually conspicuous<br>Slightly sectile, laminæ flexible | 3.4<br>3.5 | Characteristic lemon yellow color. Frequently disseminated in clay or dolomite. With realgar, stibnite, barite, calcite. |
| 1.5<br>2. | Orange yellow | C—Clinopinacoidal, basal, not conspicuous<br>F—Conchoidal<br>Slightly sectile | 3.4<br>3.6 | Redder in color than orpiment. Disseminated in clay or dolomite. With orpiment, stibnite, native arsenic, pyrite, barite, calcite. |
| 1.5<br>2.5 | Pale yellow | C—Indistinct<br>C—Conchoidal<br>Brittle | 1.9<br>2.1 | Independent beds in gypsum, limestone; in lava, result of volcanic exhalations. With celestite, anhydrite, aragonite, clay, metallic sulphides. |

**Streak—Red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Wulfenite**<br>$PbMoO_4$<br>**259** | Tetragonal<br>**C**—Square, thin tabular; more rarely pyramidal<br>**M**—Coarse, fine grained | Greasy<br>Adamantine<br>Transparent to translucent | Wax yellow<br>Orange yellow<br>Brown |
| **Vanadinite**<br>$Pb_5Cl(VO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, small, at times skeletal<br>**M**—Compact, globular, fibrous, crusts | Greasy<br>Translucent to opaque | Straw yellow<br>Brownish yellow<br>Reddish brown |

**Streak—Red, brown, or yellow**

| | | | |
|---|---|---|---|
| **LIMONITE,** varieties<br>*Compact*<br>$Fe_2O_3.H_2O$ *Bog iron ore*<br>*Brown clay ironstone*<br>**235** | **C**—Always pseudomorphs, commonly after pyrite, marcasite, siderite<br>**M**—Compact, stalactitic, botryoidal, nodular; often with internal, radial fibrous structure; porous, pisolitic, oolitic | Metallic<br>Dull<br>Opaque | Yellowish brown<br>Dark brown |
| **SIDERITE**<br>$FeCO_3$<br>**248** | Hexagonal<br>**C**—Rhombohedral, curved or saddle-shaped<br>**M**—Cleavable, granular, compact, botryoidal, rarely fibrous | Vitreous<br>Pearly<br>Dull<br>Translucent to nearly opaque | Light brown<br>Reddish brown<br>Dark brown |
| **SPHALERITE**<br>ZnS<br>**205** | Cubic<br>**C**—Tetrahedral, common<br>**M**—Cleavable, fine or coarse grained, compact | Greasy<br>Submetallic<br>Transparent to opaque | Honey yellow<br>Yellowish brown<br>Reddish brown |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.** | Lemon yellow<br>Pale yellow | C—Indistinct<br>F—Conchoidal, uneven<br>Brittle | 6.3<br>7. | Square plates, sometimes with forms of the third order. With lead minerals—galena, pyromorphite, vanadinite. |
| **3.** | Pale yellow<br>Yellow | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.7<br>7.2 | Crystal faces smooth with sharp edges. With lead minerals, but never in large quantities. |

**Hardness over 3**

| | | | | |
|---|---|---|---|---|
| **3.**<br>**5.5** | Yellowish brown | F—Conchoidal, splintery, earthy<br>Brittle | 3.4<br>4. | Often with black varnish-like surface and passing into soft, yellow ocherous variety. *Compact limonite*, massive with fibrous structure, rather pure; *bog iron ore*, porous; *brown clay ironstone*, massive or concretionary, impure from clay, sand. |
| **3.5**<br>**4.** | Pale yellow<br>Yellowish brown | C—Rhombohedral, conspicuous<br>F—Conchoidal<br>Brittle | 3.7<br>3.9 | Curved crystals and rhombohedral cleavage characteristic. In ore deposits; beds and concretions in limestones and shales. With pyrite, chalcopyrite, galena, tetrahedrite, cryolite. |
| **3.5**<br>**4.** | Pale yellow<br>Light brown | C—Dodecahedral, usually conspicuous<br>F—Conchoidal<br>Brittle | 3.9<br>4.2 | Distinguished from siderite by crystallization, more greasy luster, and cleavage. Color and streak vary with impurities. Extensively in limestones. With galena, chalcopyrite, pyrite, rhodochrosite, barite, fluorite. |

Streak—Red, brown, or yellow

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **PYROMORPHITE**<br>$Pb_5Cl(PO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, thick tabular, rounded and barrel-shaped; acicular<br>**M**—Globular, reniform, disseminated, crusts | Greasy<br>Adamantine<br>Translucent to opaque | Wax yellow<br>Green yellow<br>Yellowish brown |
| **Zincite**<br>ZnO<br>**228** | Hexagonal<br>**C**—Small, rare<br>**M**—Compact, granular, foliated | Adamantine<br>Vitreous<br>Translucent to opaque | Orange yellow<br>Reddish yellow |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long fibrous, bladed, stalky; often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Greasy<br>Submetallic<br>Translucent to opaque | Reddish brown<br>Hair brown<br>Pale yellow |
| **WOLFRAMITE**<br>$(Fe,Mn)WO_4$<br>**261** | Monoclinic<br>**C**—Thick tabular, short columnar, often large<br>**M**—Bladed, curved lamellar, granular, compact | Submetallic<br>Opaque | Reddish brown<br>Dark brown |
| **Ferberite**<br>$FeWO_4$<br>**261** | Monoclinic<br>**C**—Wedge shaped, short prismatic, tabular<br>**M**—Fan shaped aggregates, bladed, granular, compact | Submetallic<br>Opaque | Brown<br>Blackish brown |
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Adamantine<br>Submetallic<br>Translucent to opaque | Reddish brown<br>Yellowish brown<br>Dark brown |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.5<br>4. | Yellow<br>Greenish yellow | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.5<br>7.1 | Common alteration product of lead minerals. With galena, cerussite, barite, limonite. |
| 4.<br>4.5 | Orange yellow<br>Reddish yellow | C—Basal, sometimes conspicuous<br>F—Uneven<br>Brittle | 5.4<br>5.7 | Recognized by associates. With calcite, franklinite (black), willemite (yellow to green), rhodonite (flesh red). On exposure becomes coated with the white carbonate. |
| 4.5<br>5.5 | Yellowish brown | C—Clinopinacoidal, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and high specific gravity characteristic. In quartz veins. With wolframite, fluorite, pyrite, scheelite. galena, tetrahedrite. |
| 5.<br>5.5 | Reddish brown<br>Dark brown | C—Clinopinacoidal, conspicuous<br>F—Uneven<br>Brittle | 7.1<br>7.5 | Distinguished from huebnerite by streak. Powder may be slightly magnetic. With cassiterite, quartz, mica, apatite, scheelite, molybdenite, huebnerite. |
| 5.<br>5.5 | Brown<br>Dark brown | C—Clinopinacoidal, perfect<br>F—Uneven<br>Brittle | 7.5 | In granites and pegmatites. With quartz, chalcopyrite, galena, scheelite. |
| 6.<br>7. | Pale yellow<br>Pale brown | C—Prismatic, pyramidal, not conspicuous<br>F—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often in fine hair-like inclusions. With quartz, feldspar, hematite, ilmenite, chlorite, brookite. |

**Streak—Red, brown, or yellow**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CASSITERITE**<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic; knee-shaped twins quite common<br>**M**—Compact, reniform, botryoidal, rounded pebbles, often with internal, radial fibrous structure,—*wood tin* | Adamantine<br>Greasy<br>Dull<br>Translucent to opaque | Reddish<br>Yellowish<br>brown<br>Dark brown |
| **SPINEL,** variety *Picotite*<br>$(Mg,Fe)_2(Al,Cr)_2O_4$<br>**268** | Cubic<br>**C**—Octahedral, small<br>**M**—Compact, granular, disseminated grains | Vitreous<br>Dull<br>Nearly opaque | Yellowish brown<br>Greenish brown<br>Brown |

**Streak—Uncolored, white or light gray**

| | | | |
|---|---|---|---|
| **Cerargyrite** (Horn silver)<br>AgCl<br>**238** | Cubic<br>**C**—Rare<br>**M**—Wax-like crusts and coatings; stalactitic, dendritic | Waxy<br>Greasy<br>Transparent to translucent | Yellowish<br>Brownish |
| **TRIPOLITE** (Opal)<br>$SiO_2.xH_2O$<br>**234** | Amorphous<br>**M**—Porous, earthy, chalk-like | Vitreous<br>Dull<br>Translucent to opaque | Yellow<br>Yellowish brown<br>Brown |
| **KAOLINITE** (Kaolin)<br>$H_4Al_2Si_2O_9$<br>**301** | Monoclinic<br>**C**—Scaly, hexagonal or orthorhombic outline, rare<br>**M**—Compact, friable, mealy, clay-like | Dull<br>Pearly<br>Earthy<br>Opaque to translucent | Yellowish<br>Brownish |

**Hardness over 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>7. | Pale brown<br>Pale yellow | C—Indistinct<br>F—Uneven<br>Brittle | 6.8<br>7.2 | Recognized by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits as *stream tin*. With quartz, mica, wolframite, arsenopyrite, molybdenite, tourmaline, fluorite, chlorite. |
| 7.5<br>8. | Pale brown | C—Indistinct<br>F—Conchoidal<br>Brittle | 4.1 | Commonly in basic igneous rocks, especially olivine-bearing types. With serpentine, olivine, corundum, magnetite, garnet. |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>1.5 | White, shiny<br>Gray, shiny | C—None<br>F—Conchoidal<br>Highly sectile | 5.5<br>5.6 | Cuts like wax, yielding shiny surfaces; on exposure turns violet, brown, or black. With silver minerals, especially argentite, native silver; also limonite. calcite, barite. |
| 1.<br>2.5 | White<br>Gray | F—Earthy<br>Friable | 2.1<br>2.3 | Apparently very soft, but fine particles scratch glass. Resembles kaolinite, but gritty and not plastic. Due to impurities may have clay odor. |
| 1.<br>2.5 | White<br>Yellowish white | C—Basal,—scales<br>F—Earthy<br>Brittle | 2.2<br>2.6 | Not gritty like tripolite. Very strong clay odor when breathed upon. Usually adheres to tongue and becomes plastic when moistened. Greasy feel. With quartz, feldspar, corundum, topaz. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **TALC,** variety *Soapstone* or *steatite* $H_2Mg_3Si_4O_{12}$ **299** | Monoclinic **M**—Compact, globular, granular | Greasy Pearly Translucent to opaque | Yellowish Yellowish brown Brownish |
| **Asbestos,** variety *Chrysotile* $H_4Mg_3Si_2O_9$ **298** | Orthorhombic ? **M**—Fibrous, coarse or fine; felted | Silky Greasy Opaque | Yellowish Brownish |
| variety *Amphibole* Silicate of Ca, Mg, Fe, Al, etc. **311** | Monoclinic **M**—Fibrous, coarse or fine; felted; compact, leather- or cork-like | Silky Dull Opaque | Yellowish Brownish |
| **SODA NITER** (Chile saltpeter) $NaNO_3$ **241** | Hexagonal **C**—Rare **M**—Granular, crusts, efflorescences | Vitreous Transparent | Yellowish Lemon yellow Reddish brown |
| **GYPSUM,** varieties *Selenite* *Satin spar* *Ordinary* $CaSO_4.2H_2O$ **264** | Monoclinic **C**—Tabular, prismatic; swallow tail twins **M**—Cleavable, coarse and fine grained, fibrous foliated, earthy | Pearly Vitreous Silky Dull Transparent to opaque | Yellow Honey yellow Brown |
| **SULPHUR** S **193** | Orthorhombic **C**—Pyramidal, tabular **M**—Compact, granular, fibrous, earthy, crusts | Adamantine Greasy Translucent | Straw yellow Brownish yellow Reddish yellow |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.<br>2.5 | White<br>Yellowish white | F—Uneven, splintery<br>Sectile | 2.6<br>2.8 | Greasy or soapy feel important. *Soapstone* or *steatite*, coarse to fine, granular, more or less impure. Hardness varies. With serpentine, chlorite, dolomite, magnesite, actinolite. |
| 1.<br>3. | White | F—Fibrous<br>Flexible | 1.<br>2.5 | Delicate, fine, parallel, flexible fibers, perpendicular to walls, easily separable —*short fibered asbestos*, compare below. In veins or seams in serpentine. |
| 1.<br>3. | White | F—Fibrous<br>Flexible, tough | 1.<br>2.5 | *Long fibered asbestos*, parallel, flexible fibers, parallel to walls. Compare above. *Mountain leather*, *mountain cork*, *mountain wood*, compact but light and tough. |
| 1.5<br>2. | White | C—Rhombohedral<br>F—Conchoidal<br>Brittle | 2.1<br>2.3 | Cooling and saline taste. Absorbs moisture readily. In deposits with gypsum, sand, clay, guano. |
| 1.5<br>2. | White | C—Clinopinacoidal, conspicuous; pyramidal, orthopinacoidal<br>F—Conchoidal, fibrous<br>Brittle, laminæ flexible | 2.2<br>2.4 | *Selenite*, crystals and cleavable plates, usually transparent; *satin spar*, fibrous with silky luster; *ordinary*, granular. In limestones and shales. With halite, celestite, sulphur, aragonite, anhydrite; ore deposits. |
| 1.5<br>2.5 | White<br>Yellowish white | C—Indistinct<br>F—Conchoidal<br>Brittle | 1.9<br>2.1 | Independent beds in gypsum, limestone; in lava, result of volcanic exhalations. With celestite, anhydrite, aragonite, clay, metallic sulphides. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **HALITE** (Rock salt)<br>NaCl<br>**236** | Cubic<br>**C**—Cubes, often skeletal or hopper-shaped<br>**M**—Compact, cleavable, granular, fibrous, stalactitic, crusts | Vitreous<br>Transparent to translucent | Yellow<br>Yellowish brown<br>Brownish |
| **MICAS**<br>**MUSCOVITE** (Isinglass)<br>$H_2KAl_3(SiO_4)_3$<br>**295** | Monoclinic<br>**C**—Tabular, pyramidal, with orthorhombic or hexagonal outline; often large and rough<br>**M**—Scales, plates; foliated and plumose aggregates | Vitreous<br>Pearly<br>Transparent to translucent | Light yellow<br>Yellowish brown<br>Light brown |
| **PHLOGOPITE**<br>$(K,H)_3Mg_3Al(SiO_4)_3$<br>**294** | Monoclinic<br>**C**—Prismatic, tabular, with hexagonal or orthorhombic outline; often large and coarse<br>**M**—Plates, disseminated scales | Pearly<br>Submetallic<br>Transparent to translucent | Yellow<br>Yellowish brown<br>Brown |
| **APATITE**, variety *Phosphate rock*<br>$Ca_5F(PO_4)_3$, chiefly<br>**273** | Hexagonal<br>**M**—Compact, fibrous, nodular, reniform, earthy | Dull<br>Opaque | Brown |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 2.<br>2.5 | White | C—Cubic, perfect, conspicuous<br>F—Conchoidal<br>Brittle | 2.1<br>2.3 | Pigment usually iron oxide. May absorb moisture and become damp. Characteristic cubical cleavage and saline taste. With shale, gypsum, anhydrite. |
| 2.<br>3. | White | C—Basal, perfect, conspicuous<br>Tough laminæ very elastic | 2.8<br>3.1 | Lighter colored than phlogopite. Structure, perfect cleavage, and elasticity important. Crystals may show distinct partings perpendicular to cleavage—*ruled mica*. In granitic rocks, schists, limestones. With feldspar, quartz, tourmaline, beryl, garnet. |
| 2.<br>3. | White | C—Basal, perfect, conspicuous<br>Tough, laminæ very elastic | 2.8<br>3.1 | Usually amber brown or bronze in color. When cleavage laminæ are held close to the eye in viewing a source of light a star-like form is sometimes observed. Especially characteristic of crystalline limestones, dolomites, schists. With pyroxenes, amphiboles, serpentine. |
| 2.<br>3. | White | F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | More or less impure masses, frequently resembling compact limestone. Independent beds, nodules, concretions. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **BARITE** (Heavy spar)<br>$BaSO_4$<br>**256** | Orthorhombic<br>**C**—Tabular, prismatic, very common; crested divergent groups<br>**M**—Compact, lamellar, fibrous, cleavable, reniform | Vitreous<br>Pearly<br>Transparent to opaque | Yellowish<br>Brownish<br>Dark brown |
| **CALCITE**, varieties<br>*Dog tooth spar*<br>$CaCO_3$ *Nail head spar*<br>*Limestone*<br>*Marble*<br>*Calcareous tufa*<br>*Travertine*<br>*Stalactites, etc.*<br>**242** | Hexagonal<br>**C**—Scalenohedral, rhombohedral; prismatic; tabular, acicular; may be highly modified and twinned<br>**M**—Cleavable, granular, fibrous, banded, stalactitic, oölitic, porous, compact, crusts, shells | Vitreous<br>Dull<br>Transparent to nearly opaque | Honey yellow<br>Yellowish brown<br>Dark brown |
| **Wulfenite**<br>$PbMoO_4$<br>**259** | Tetragonal<br>**C**—Square, thin tabular; more rarely pyramidal<br>**M**—Coarse, fine grained | Greasy<br>Adamantine<br>Transparent to translucent | Wax yellow<br>Orange yellow<br>Brown |
| **Vanadinite**<br>$Pb_5Cl(VO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, small, at times skeletal<br>**M**—Compact, globular, fibrous, crusts | Greasy<br>Translucent to opaque | Straw yellow<br>Brownish yellow<br>Reddish brown |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **BARITE** (Heavy spar)<br>$BaSO_4$<br>**256** | Orthorhombic<br>**C**—Tabular, prismatic, very common; crested and divergent groups<br>**M**—Compact, lamellar, fibrous, cleavable, reniform | Vitreous<br>Pearly<br>Transparent to opaque | Yellowish<br>Brownish<br>Dark brown |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 2.5<br>3. | White | C—Basal, prismatic, usually conspicuous<br>F—Uneven<br>Brittle | 4.3<br>4.7 | Characterized by rather high specific gravity and cleavages. In metalliferous veins; pockets, lenticular masses in limestones. With galena, sphalerite, fluorite, chalcopyrite; manganese and iron minerals. |
| 3. | White | C—Rhombohedral, usually conspicuous<br>F—Conchoidal<br>Brittle | 2.7 | Often in extensive deposits. Rhombohedral cleavage characteristic especially on crystals. Cleavage surfaces often striated. Very strong double refraction easily observed when transparent. To distinguish varieties, see reference. |
| 3. | White<br>Yellowish white | C—Pyramidal, indistinct<br>F—Conchoidal, uneven<br>Brittle | 6.3<br>7. | Square plates sometimes with forms of the third order. With lead minerals—galena, pyromorphite, vanadinite. |
| 3. | White<br>Yellowish white | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.7<br>7.2 | Crystal faces smooth with sharp edges. With lead minerals, but never in large quantities. |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.<br>3.5 | White | C—Basal, prismatic, usually conspicuous<br>F—Uneven<br>Brittle | 4.3<br>4.7 | Characterized by rather high specific gravity and cleavages. In metalliferous veins; pockets, lenticular masses in limestone. With galena, sphalerite, fluorite, chalcopyrite; manganese and iron minerals. |

**Streak—Uncolored, white or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CERUSSITE**<br>$PbCO_3$<br>**251** | Orthorhombic<br>**C**—Tabular, prismatic, pyramidal; pseudo-hexagonal; clusters and star-shaped groups<br>**M**—Interlaced bundles, granular, stalactitic, compact | Adamantine<br>Greasy<br>Silky<br>Transparent to translucent | Yellow<br>Yellowish brown |
| **STILBITE** (Zeolite)<br>$(Ca,Na_2)Al_2Si_6O_{16}.6HO$<br>**326** | Monoclinic<br>**C**—Twinned, sheaf-like, radial or globular aggregates | Vitreous<br>Pearly<br>Transparent to translucent | Yellowish<br>Yellowish brown<br>Brownish |
| **SERPENTINE**<br>$H_4Mg_3Si_2O_9$<br>**297** | Orthorhombic ?<br>**C**—Unknown<br>**M**—Compact, columnar, fibrous, lamellar, granular | Greasy<br>Waxy<br>Translucent to opaque | Greenish brown<br>Greenish yellow<br>Yellowish brown |
| **APATITE,** variety *Phosphate rock*<br>$Ca_5F(PO_4)_3$, chiefly<br>**273** | Hexagonal<br>**M**—Compact, fibrous, nodular, reniform | Dull<br>Opaque | Brown |
| **Wavellite**<br>$(Al.OH)_3(PO_4)_2.5H_2O$<br>**276** | Orthorhombic<br>**C**—Capillary, small<br>**M**—Crusts, globular, hemispherical aggregates, with radial fibrous structure | Vitreous<br>Translucent | Yellow<br>Brown |
| **DOLOMITE**<br>$CaMg(CO_3)_2$<br>**245** | Hexagonal<br>**C**—Rhombohedral, with curved surfaces<br>**M**—Coarsely crystalline, compact, granular, friable | Vitreous<br>Transparent to translucent | Yellowish brown<br>Grayish brown<br>Dark brown |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.**<br>**3.5** | White<br>Gray | C—Indistinct<br>F—Conchoidal<br>Brittle | 6.4<br>6.6 | Twinning, structure, luster, and specific gravity characteristic. With lead minerals—galena, pyromorphite, anglesite; also malachite, limonite. |
| **3.**<br>**4.** | White | C—Indistinct<br>F—Uneven<br>Brittle | 2.1<br>2.2 | Radial and sheaf-like structure important. In basic igneous rocks and ore deposits. With chabazite, apophyllite, datolite, calcite. |
| **3.**<br>**4.** | White | F—Conchoidal, splintery<br>Brittle | 2.5<br>2.8 | Smooth and greasy feel. Often spotted, clouded, multi-colored. Sometimes crossed by seams of asbestos (*chrysotile*). With magnesite, chromite, garnierite, pyrope, platinum, calcite. |
| **3.**<br>**5.** | White | F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | More or less impure masses, frequently resembling compact, brown limestone. Independent beds, nodules, concretions. |
| **3.5**<br>**4.** | White | C—Pinacoidal, domatic<br>F—Uneven, fibrous<br>Brittle | 2.3<br>2.4 | Secondary mineral occurring on surfaces of rocks or minerals, as crystalline crusts with pronounced radial fibrous structure. |
| **3.5**<br>**4.** | White<br>Gray | C—Rhombohedral, perfect (crystals)<br>F—Conchoidal<br>Brittle | 2.9 | Crystals generally curved or saddle-shaped. *Marble* includes some compact varieties. Independent beds; in fissures and cavities; with ore deposits. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **ARAGONITE**<br>$CaCO_3$<br>**249** | Orthorhombic<br>**C**—Chisel- or spear-shaped; pseudohexagonal prisms; radial, columnar, acicular aggregates<br>**M**—Stalactitic, reniform, crusts, oölitic | Vitreous<br>Resinous<br>Transparent to translucent | Wine yellow<br>Yellowish brown |
| **STRONTIANITE**<br>$SrCO_3$<br>**250** | Orthorhombic<br>**C**—Spear-shaped, columnar, acicular; often in divergent groups<br>**M**—Granular, compact, botryoidal, fibrous | Vitreous<br>Greasy<br>Transparent to translucent | Yellow<br>Yellowish brown<br>Brown |
| **SIDERITE**<br>$FeCO_3$<br>**248** | Hexagonal<br>**C**—Rhombohedral, curved or saddle-shaped, common<br>**M**—Cleavable, granular, compact, botryoidal, rarely fibrous | Vitreous<br>Pearly<br>Dull<br>Translucent to nearly opaque | Light brown<br>Reddish brown<br>Dark brown |
| **SPHALERITE**<br>$ZnS$<br>**205** | Cubic<br>**C**—Tetrahedral, common<br>**M**—Cleavable, fine and coarse grained, compact | Resinous<br>Submetallic<br>Translucent to opaque | Honey yellow<br>Yellowish brown<br>Reddish brown |
| **PYROMORPHITE**<br>$Pb_5Cl(PO_4)_3$<br>**275** | Hexagonal<br>**C**—Prismatic, thick tabular, rounded and barrel-shaped; acicular<br>**M**—Globular, reniform, disseminated, crusts | Greasy<br>Adamantine<br>Translucent to opaque | Wax yellow<br>Greenish yellow<br>Yellowish brown |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.5<br>4. | White<br>Gray | C—Pinacoidal, prismatic<br>F—Conchoidal<br>Brittle | 2.9<br>3. | Twins common, often pseudohexagonal—prism and striated base. In cracks and cavities; with ore deposits; deposition from hot springs; in shells. With gypsum, celestite, sulphur, siderite, zeolites. |
| 3.5<br>4. | White<br>Gray | C—Prismatic, indistinct<br>F—Uneven<br>Brittle | 3.6<br>3.8 | Structure similar to aragonite. Divergent columnar masses and higher specific gravity characteristic. In ore deposits; independent beds. With galena, barite, calcite. |
| 3.5<br>4. | Gray<br>White | C—Rhombohedral, conspicuous<br>F—Conchoidal<br>Brittle | 3.7<br>3.9 | Distinguished from sphalerite by curved crystals and rhombohedral cleavage. In ore deposits; beds and concretions in limestones and shales. With pyrite, chalcopyrite, galena, tetrahedrite, cryolite. |
| 3.5<br>4. | White<br>Yellowish white | C—Dodecahedral, usually conspicuous<br>F—Conchoidal<br>Brittle | 3.9<br>4.2 | Resinous luster and cleavage important. Color and streak vary with impurities. Extensively in limestones. With galena, chalcopyrite, pyrite, barite, fluorite, rhodochrosite. |
| 3.5<br>4. | White<br>Yellowish white | C—None<br>F—Conchoidal, uneven<br>Brittle | 6.5<br>7.1 | Common alteration product of lead minerals. With galena, cerussite, barite, limonite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **FLUORITE** (Fluor spar)<br>$CaF_2$<br>**239** | Cubic<br>**C**—Cubes, alone or modified, well developed<br>**M**—Cleavable, granular, fibrous | Vitreous<br>Transparent to nearly opaque | Wine yellow<br>Yellowish brown<br>Brown |
| **Scheelite**<br>$CaWO_4$<br>**259** | Tetragonal<br>**C**—Pyramidal, small, more rarely tabular<br>**M**—Drusy crusts, reniform, granular, compact | Greasy<br>Adamantine<br>Transparent to translucent | Pale yellow<br>Yellowish brown<br>Grayish brown |
| **APATITE**<br>$Ca_5F(PO_4)_3$<br>**273** | Hexagonal<br>**C**—Prismatic, thick tabular, sometimes large, with rounded edges<br>**M**—Compact, fibrous, nodular, reniform | Greasy<br>Vitreous<br>Translucent to opaque | Brown<br>Greenish brown<br>Reddish brown<br>Yellow |
| **HEMIMORPHITE** (Calamine)<br>$H_2Zn_2SiO_5$<br>**280** | Orthorhombic<br>**C**—Thin tabular, pyramidal, hemimorphic, highly modified<br>**M**—Compact, globular, granular, stalactitic, cellular, earthy | Vitreous<br>Dull<br>Transparent to translucent | Yellow<br>Yellowish brown<br>Brown |
| **Huebnerite**<br>$MnWO_4$<br>**260** | Monoclinic<br>**C**—Long fibrous, bladed, stalky; often divergent, without good terminations<br>**M**—Compact, lamellar, granular | Resinous<br>Submetallic<br>Translucent to opaque | Reddish brown<br>Hair brown<br>Pale yellow |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **4.** | White | C—Octahedral, perfect, conspicuous<br>Brittle | 3.<br>3.2 | Recognized by crystal form, octahedral cleavage, and hardness. Common gangue of metallic ores, especially galena, sphalerite, cassiterite; also with calcite, barite. |
| **4.5** | White | C—Pyramidal, not conspicuous<br>F—Conchoidal, uneven<br>Brittle | 5.9<br>6.2 | Small, well developed octahedral-like crystals, usually on quartz; when massive high specific gravity important. With cassiterite, wolframite, fluorite, apatite, molybdenite. |
| **4.5**<br>**5.** | White | C—Basal, imperfect<br>F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | Crystals may be vertically striated and have fused appearance. Color unevenly distributed, often with greenish spots. In crystalline limestones; metalliferous deposits; igneous rocks. With quartz, cassiterite, fluorite, wolframite. |
| **4.5**<br>**5.** | White | C—Prismatic<br>F—Uneven, conchoidal<br>Brittle | 3.3<br>3.5 | Crystals often in sheaf-like groups or druses in cavities. When massive, often porous or cellular. In limestones. With sphalerite, galena, and especially smithsonite. |
| **4.5**<br>**5.5** | Greenish gray | C—Clinopinacoidal, conspicuous<br>Brittle | 6.7<br>7.3 | Structure, cleavage, and specific gravity characteristic. In quartz veins. With wolframite, fluorite, pyrite, scheelite, galena, tetrahedrite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **SMITHSONITE**<br>$ZnCO_3$<br>**247** | Hexagonal<br>**C**—Small, usually as druses or crusts<br>**M**—Botryoidal, stalactitic, fibrous, compact, cellular, granular | Vitreous<br>Dull<br>Translucent to nearly opaque | Brown<br>Yellowish brown<br>Orange yellow |
| **Natrolite** (Zeolite)<br>$Na_2Al(AlO)(SiO_3)_3.2H_2O$<br>**324** | Orthorhombic<br>**C**—Slender prismatic, nearly square, radial or interlacing groups<br>**M**—Fibrous, granular, compact | Vitreous<br>Silky<br>Transparent to translucent | Yellowish |
| **TITANITE** (Sphene)<br>$CaTiSiO_5$<br>**323** | Monoclinic<br>**C**—Wedge- or envelope-shaped when disseminated; tabular or prismatic when attached<br>**M**—Compact, lamellar | Vitreous<br>Greasy<br>Transparent to opaque | Brown<br>Reddish brown<br>Yellow |
| **Monazite**<br>$(Ce,La,Di)PO_4$<br>**272** | Monoclinic<br>**C**—Thick tabular, square prismatic<br>**M**—Angular fragments, rolled grains | Greasy<br>Vitreous<br>Transparent to opaque | Reddish brown<br>Yellowish brown<br>Honey yellow |
| **Cancrinite**<br>$H_6(Na_2,Ca)_4(NaCO_3)_2$-$Al_3Si_3O_{36}$<br>**302** | Hexagonal<br>**C**—Prismatic, rare<br>**M**—Compact, lamellar, columnar, disseminated | Greasy<br>Vitreous<br>Pearly<br>Translucent to transparent | Yellow<br>Brownish yellow |
| **BRONZITE** (Pyroxene)<br>$(Mg,Fe)_2(SiO_3)_2$<br>**304** | Orthorhombic<br>**C**—Prismatic, rare<br>**M**—Fibrous, lamellar, compact | Bronzy<br>Silky<br>Translucent to opaque | Bronze brown<br>Yellowish brown |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>6. | White<br>Gray | C—Rhombohedral, not often observed<br>F—Uneven, splintery<br>Brittle | 4.1<br>4.5 | Cellular varieties called *dry bone*. Often mixed with sand, clay, limonite, calcite. With zinc minerals, especially sphalerite, hemimorphite. Frequently pseudomorphous after calcite. |
| 5.<br>5.5 | White | C—Prismatic, perfect<br>F—Uneven<br>Brittle | 2.2<br>2.3 | Crystals have nearly square cross-section. In basalts and phonolites. With chabazite, analcite, apophyllite, stilbite, datolite. |
| 5.<br>5.5 | White<br>Gray | C—Prismatic, conspicuous, parting often noted<br>F—Conchoidal<br>Brittle | 3.4<br>3.6 | With feldspars, pyroxenes, amphiboles, chlorite, scapolite, zircon. |
| 5.<br>5.5 | White | C—Basal<br>F—Conchoidal, uneven<br>Brittle | 4.9<br>5.3 | Crystals commonly small, highly modified; rounded grains in sand. With quartz, magnetite, zircon, garnet, gold chromite, diamond. |
| 5.<br>6. | White | C—Prismatic<br>F—Uneven<br>Brittle | 2.4<br>2.5 | Easily recognized by associates—nephelite, sodalite, biotite, feldspar, titanite. |
| 5.<br>6. | White<br>Grayish | C—Prismatic, pinacoidal, conspicuous<br>F—Uneven<br>Brittle | 3.2<br>3.5 | Cleavage surfaces usually fibrous or lamellar, irregular or wavy, with distinct bronzy luster; darker than enstatite. In basic igneous rocks. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **RHODONITE** (Pyroxene)<br>$MnSiO_3$<br>**309** | Triclinic<br>**C**—Tabular, prismatic rounded edges<br>**M**—Cleavable, granular, disseminated grains | Vitreous<br>Dull<br>Translucent to opaque | Yellowish Brownish |
| **Willemite** (Troostite)<br>$Zn_2SiO_4$<br>**289** | Hexagonal<br>**C**—Prismatic<br>**M**—Compact, granular, disseminated grains | Greasy<br>Vitreous<br>Transparent to opaque | Yellow<br>Greenish yellow<br>Brown |
| **OPAL,** varieties<br>*Precious opal*<br>$SiO_2.xH_2O$ *Wood opal*<br>*Opal jasper*<br>*Silicious sinter*<br>**232** *Tripolite* | Amorphous<br>**M**—Compact, reniform, botryoidal, porous, earthy | Vitreous<br>Greasy<br>Dull<br>Translucent to opaque | Yellow<br>Yellowish brown<br>Brown |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **ORTHOCLASE** (Feldspar)<br>$KAlSi_3O_8$<br>**316** | Monoclinic<br>**C**—Prismatic, thick tabular; twins; often large<br>**M**—Cleavable, granular, disseminated | Vitreous<br>Pearly<br>Translucent to opaque | Pale yellow<br>Brownish yellow |
| **Chondrodite**<br>$[Mg(F,OH)]_2Mg_3(SiO_4)_2$<br>**286** | Monoclinic<br>**C**—Small, highly modified, rare<br>**M**—Disseminated grains, compact | Vitreous<br>Greasy<br>Translucent - to opaque | Reddish brown<br>Yellowish brown<br>Honey yellow |
| **Sillimanite** (Fibrolite)<br>$Al_2SiO_5$<br>**282** | Orthorhombic<br>**C**—Long, thin, needle-like<br>**M**—Fibrous, columnar, radiating | Vitreous<br>Silky<br>Transparent to translucent | Hair brown<br>Grayish brown |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.**<br>**6.** | White | **C**—Prismatic, basal<br>**F**—Conchoidal, uneven<br>Tough, crystals brittle | 3.4<br>3.7 | On exposure may be stained brown or black. *Fowlerite*, contains zinc. With franklinite, zincite, willemite, calcite, iron ores. |
| **5.**<br>**6.** | White | **C**—Basal, prismatic<br>**F**—Uneven<br>Brittle | 3.9<br>4.3 | Crystals of willemite small, of troostite, manganiferous variety, often large. Characterized by associates—franklinite, zincite, rhodonite, calcite. |
| **5.5**<br>**6.** | White | **F**—Conchoidal, conspicuous when compact; earthy<br>Brittle | 2.1<br>2.3 | *Precious opal*, play of colors; *wood opal*, woody structure; *opal jasper*, greasy, resembling jasper; *silicious sinter*, porous; *tripolite*, earthy, gritty. |

**Hardness over 6**

| | | | | |
|---|---|---|---|---|
| **6.**<br>**6.5** | White | **C**—Basal clinopinacoidal, conspicuous—90°<br>**F**—Conchoidal, uneven<br>Brittle | 2.5<br>2.6 | Characterized by rectangular cleavages and absence of twinning striations. In granitic rocks. With quartz, other feldspars, mica, hornblende. |
| **6.**<br>**6.5** | White | **C**—Basal, indistinct<br>**F**—Conchoidal, uneven<br>Brittle | 3.1<br>3.3 | Associates important. In crystalline limestones and dolomites. With spinel, vesuvianite, pyroxenes, mica. |
| **6.**<br>**7.** | White | **C**—Macropinacoidal<br>**F**—Uneven<br>Brittle | 3.2<br>3.3 | Crystals often slender, bent, striated, with rounded edges, without good terminations, and interlaced. In metamorphic rocks—mica, schist, gneiss. With andalusite, garnet. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **EPIDOTE**<br>$Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$<br>**286** | Monoclinic<br>**C**—Prismatic, elongated and deeply striated parallel to *b* axis; usually terminated on one end only<br>**M**—Columnar; fibrous, parallel and divergent; granular | Vitreous<br>Transparent to opaque | Greenish brown<br>Greenish yellow<br>Yellow |
| **RUTILE**<br>$TiO_2$ or $TiTiO_4$<br>**224** | Tetragonal<br>**C**—Prismatic, vertically striated; twinned, yielding knee-shaped or rosette forms<br>**M**—Compact, disseminated | Adamantine<br>Submetallic<br>Translucent to opaque | Reddish brown<br>Yellowish brown<br>Dark brown |
| **CASSITERITE**<br>$SnO_2$ or $SnSnO_4$<br>**226** | Tetragonal<br>**C**—Thick prismatic; knee-shaped twins quite common<br>**M**—Reniform, botryoidal, compact, rounded pebbles, often with internal radial, fibrous structure, *wood tin* | Adamantine<br>Greasy<br>Dull<br>Translucent to opaque | Reddish brown<br>Yellowish brown<br>Dark brown |
| **VESUVIANITE**<br>$Ca_6[Al(OH,F)]Al_2(SiO_4)_5$<br>**288** | Tetragonal<br>**C**—Short prismatic<br>**M**—Compact, granular; aggregates with parallel or divergent striations or furrows | Vitreous<br>Greasy<br>Translucent to opaque | Brown<br>Greenish brown<br>Sulphur yellow |
| **GARNET,** varieties<br>$R_3''R_2'''(SiO_4)_3$<br>R″ = Ca,Fe,Mg,Mn<br>R‴ = Al,Fe<br>**290** | *Grossularite*<br>*Spessartite*<br>*Almandite*<br>*Andradite*<br>Cubic<br>**C**—Dodecahedrons, tetragonal trisoctahedrons, alone or in combination<br>**M**—Granular, compact, lamellar, disseminated grains, sand | Vitreous<br>Transparent to opaque | Yellow<br>Cinnamon brown<br>Reddish brown |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **6.**<br>**7.** | White<br>Grayish | **C**—Basal<br>**F**—Uneven<br>Brittle | 3.3<br>3.5 | Crystals often darker than when massive. With quartz, feldspar, vesuvianite, hornblende, pyroxenes, magnetite, native copper. |
| **6.**<br>**7.** | Gray<br>Yellowish white<br>Brownish white | **C**—Prismatic, pyramidal, not conspicuous<br>**F**—Uneven<br>Brittle | 4.2<br>4.3 | Not as heavy as cassiterite. Often in fine hair-like inclusions. With quartz, feldspar, hematite, ilmenite, chlorite. |
| **6.**<br>**7.** | White<br>Yellowish white<br>Brownish white | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 6.8<br>7. | Distinguished by high specific gravity. In veins cutting granite, gneiss; in alluvial deposits as *stream tin*. With quartz, wolframite, scheelite, molybdenite, tourmaline, fluorite, mica, chlorite. |
| **6.5** | White | **C**—Indistinct<br>**F**—Uneven<br>Brittle | 3.3<br>3.5 | In crystalline limestone, gneiss, schist. With garnet, tourmaline chondrodite, wollastonite, epidote, pyroxenes. |
| **6.5**<br>**7.5** | White | **C**—Dodecahedral, usually indistinct<br>**F**—Conchoidal, uneven<br>Brittle | 3.4<br>4.3 | *Grossularite*, in crystalline limestone, dolomite, with wollastonite, vesuvianite, diopside, scapolite; *spessartite*, in granitic rocks, with quartz, tourmaline, orthoclase; *almandite*, with mica, staurolite, andalusite, cyanite; *andradite*, with epidote, feldspar, nephelite, leucite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **QUARTZ,** $SiO_2$ Phanerocrystalline varieties<br>*Smoky quartz*<br>*False topaz*<br>*Aventurine*<br>*Ferruginous*<br>*Cat's eye* | Hexagonal<br>**C**—Prismatic, horizontally striated<br>**M**—Compact, granular | Vitreous<br>Greasy<br>Transparent to opaque | Yellow<br>Yellowish brown<br>Smoky brown<br>Reddish brown |
| **222** | | | |
| Cryptocrystalline varieties<br>*Chalcedony*<br>*Agate*<br>*Jasper*<br>*Flint* | Hexagonal<br>**C**—Never in crystals<br>**M**—Nodular, botryoidal, banded, concretionary, stalactitic, compact | Waxy<br>Vitreous<br>Translucent to opaque | Yellow<br>Brown<br>Blackish brown |
| **223** | | | |
| Clastic varieties<br>*Sand*<br>*Sandstone*<br>*Quartzite* | Hexagonal<br>**M**—Grains, fragments, either loose or strongly consolidated | Vitreous<br>Dull<br>Translucent to opaque | Yellow<br>Yellowish brown<br>Brown |
| **224** | | | |
| **TOURMALINE**<br>$M'_9Al_3(B.OH)_2Si_4O_{19}$<br>M′ = Na,K,Li,Mg,Fe | Hexagonal<br>**C**—Prismatic, vertically striated; terminated with broken or rhombohedral-like surfaces<br>**M**—Compact, granular | Vitreous<br>Translucent to opaque | Brown<br>Yellowish brown<br>Yellow |
| **284** | | | |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **7.** | White<br>Yellowish white<br>Brownish white | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle | 2.6 | Characteristic conchoidal fracture and glassy luster. *Smoky quartz*, smoky yellow to brownish black; *false topaz*, yellow; *aventurine*, glistening with included scales; *ferruginous*, colored by iron oxide, *cat's eye*, opalescent, due to inclusions of fibers of asbestos. |
| **7.** | White<br>Yellowish white<br>Brownish white | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle to tough | 2.6 | Not as glassy as phanerocrystalline varieties. *Chalcedony*, pale to dark brown, waxy luster; *agate*, banded or clouded; *jasper*, commonly yellow and uniform in color; *flint*, smoky or blackish brown, nodular, often with white coating. |
| **7.** | White<br>Yellowish white<br>Brownish white | C—Indistinct<br>F—Uneven<br>Brittle to tough | 2.6 | Pigment is usually ferruginous matter. *Sand*, loose, unconsolidated grains; *sandstone*, consolidated sand; *quartzite*, metamorphosed sandstone. |
| **7.**<br>**7.5** | White | C—None<br>F—Conchoidal, uneven<br>Brittle | 2.9<br>3.2 | Spherical, triangular cross-section. Commonly as contact mineral in granular limestone and dolomite. With tremolite, scapolite, vesuvianite, apatite, garnet, spinel. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **STAUROLITE**<br>$Fe(AlO)_4(Al.OH)(SiO_4)_2$<br>**279** | Orthorhombic<br>**C**—Prismatic; twins plus- (+) or X-shaped; well developed | Vitreous<br>Dull<br>Translucent to opaque | Reddish brown<br>Yellowish brown<br>Blackish brown |
| **ZIRCON**<br>$ZrSiO_4$<br>**225** | Tetragonal<br>**C**—Square prisms and bipyramids, small, well developed<br>**M**—Irregular lumps, grains | Adamantine Vitreous<br>Greasy<br>Transparent to opaque | Reddish brown<br>Dark brown<br>Brownish yellow |
| **BERYL**<br>$Be_3Al_2(SiO_3)_6$<br>**313** | Hexagonal<br>**C**—Long prismatic, often vertically striated, large<br>**M**—Columnar, granular, compact | Vitreous<br>Transparent to translucent | Pale yellow<br>Honey yellow<br>Brownish yellow |
| **SPINEL**, varieties<br>*Pleonaste*<br>*Gahnite*<br>$R''(R'''O_2)_2$<br>$R''$ = Mg,Fe,Zn<br>$R'''$ = Al,Fe<br>**267** | Cubic<br>**C**—Octahedral, well developed<br>**M**—Compact, granular, disseminated grains | Vitreous<br>Dull<br>Nearly opaque | Yellow<br>Grayish brown<br>Brown |
| **TOPAZ**<br>$Al_2(F,OH)_2SiO_4$<br>**283** | Orthorhombic<br>**C**—Prismatic, vertically striated, highly modified<br>**M**—Compact, granular, rolled fragments | Vitreous<br>Transparent to opaque | Straw yellow<br>Wine yellow<br>Yellowish brown |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **7.**<br>**7.5** | White<br>Grayish | C—Brachypinacoidal<br>F—Conchoidal, uneven<br>Brittle | 3.4<br>3.8 | Fresh crystals usually possess bright, smooth faces, when altered dull, rough, softer and with colored streak. In metamorphic rocks—gneiss, mica schist, slate. With cyanite, garnet, tourmaline, sillimanite |
| **7.5** | White | C—Indistinct<br>F—Uneven<br>Brittle | 4.4<br>4.8 | In the more acid igneous rocks—granite, syenite; alluvial deposits, with gold, spinel, corundum, garnet. *Hyacinth*, clear and transparent. |
| **7.5**<br>**8.** | White | C—Basal, indistinct<br>F—Conchoidal, uneven<br>Brittle | 2.6<br>2.8 | Crystals usually simple, prism and base. In granitic rocks, mica schists, clay slates. With quartz, feldspar, mica, chrysoberyl, topaz, cassiterite, garnet. |
| **7.5**<br>**8.** | White<br>Grayish | C—Indistinct<br>F—Conchoidal<br>Brittle | 3.6<br>4.4 | Commonly as contact mineral in granular limestone; in more basic igneous rocks; as rounded grains in placers. With calcite, chondrodite, serpentine, brucite, graphite, pyroxenes. |
| **8.** | White | C—Basal, perfect, conspicuous<br>F—Conchoidal, uneven<br>Brittle | 3.4<br>3.6 | Crystals usually developed on one end only. Color may fade on exposure. Massive varieties distinguished from quartz by higher specific gravity and basal cleavage. In veins and cavities in granitic rocks, also in placers. With cassiterite, tourmaline, fluorite, apatite, beryl, wolframite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Chrysoberyl**<br>$Be(AlO_2)_2$<br>**271** | Orthorhombic<br>**C**—Tabular; heart-shaped, pseudohexagonal twins<br>**M**—Fragments, loose, rounded grains | Vitreous<br>Greasy<br>Transparent to translucent | Yellow<br>Greenish yellow<br>Brown |
| **CORUNDUM,** varieties<br>*Oriental topaz*<br>*Common*<br>$Al_2O_3$<br>**228** | Hexagonal<br>**C**—Prismatic, tabular, pyramidal, rhombohedral; rough or rounded barrel-shaped<br>**M**—Compact, granular, lamellar | Vitreous<br>Translucent to transparent | Yellow<br>Brown |

B. MINERALS WITH NON-METALLIC LUSTER

Streak—Uncolored, white, or light gray

| | | | |
|---|---|---|---|
| **Cerargyrite** (Horn silver)<br>AgCl<br>**238** | Cubic<br>**C**—Rare<br>**M**—Wax-like crusts, coatings; stalactitic, dendritic | Waxy<br>Greasy<br>Transparent to translucent | Pearl gray<br>Grayish |
| **Asbestos,** variety<br>*Chrysotile*<br>$H_4Mg_3Si_2O_9$<br>**298** | Orthorhombic ?<br>**M**—Coarse or fine fibrous, felted | Silky<br>Silky metallic<br>Opaque | White<br>Greenish white<br>Yellowish white |
| variety<br>*Amphibole*<br>Silicate of Ca, Mg, Fe, Al, etc.<br>**311** | Monoclinic?<br>**M**—Coarse or fine fibrous, felted; compact, leather- or cork-like | Silky<br>Dull<br>Opaque | White<br>Greenish white<br>Yellowish white |

Hardness over 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **8.5** | White | C—Brachypinacoidal<br>F—Uneven, conchoidal<br>Brittle | 3.5<br>3.8 | Crystals disseminated as plates, often with feather-like or radial striations. In granite, gneiss, placers. With beryl, garnet, tourmaline, sillimanite. |
| **9.** | White | C—None, nearly rectangular basal and rhombohedral partings, conspicuous; striated<br>F—Conchoidal<br>Brittle to tough | 3.9<br>4.1 | When massive often multicolored—red, blue, green, gray. *Oriental topaz*, transparent, yellow. In limestone, granite, syenite, alluvial deposits. With magnetite, nephelite, mica, spinel, chlorite. |

## 5. COLORLESS, WHITE, OR LIGHT GRAY IN COLOR

Hardness 1 to 3

| | | | | |
|---|---|---|---|---|
| **1.**<br>**1.5** | White, shiny<br>Gray, shiny | C—None<br>F—Conchoidal<br>Highly sectile | 5.5<br>5.6 | Cuts like wax; on exposure turns violet, brown, or black. With silver minerals; also limonite, calcite, barite. |
| **1.**<br>**2.5** | White | F—Fibrous<br>Flexible | 1.<br>2.5 | *Short fibered asbestos*, delicate, fine, parallel, flexible fibers, easily separable, perpendicular to walls. Compare below. In veins or seams in serpentine. |
| **1.**<br>**2.5** | White | F—Fibrous<br>Flexible, tough | 1.<br>2.5 | *Long fibered asbestos*, parallel, flexible fibers, parallel to walls. *Mountain leather, mountain cork, mountain wood*, compact, but light and tough. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **TRIPOLITE** (Opal)<br>$SiO_2.xH_2O$<br>**234** | Amorphous<br>**M**—Porous, earthy, chalk-like | Dull<br>Opaque | Gray<br>White<br>Yellowish white |
| **KAOLINITE** (Kaolin, china clay)<br>$H_4Al_2Si_2O_9$<br>**301** | Monoclinic<br>**C**—Scaly, rare<br>**M**—Compact, friable, mealy, clay-like | Dull<br>Pearly<br>Opaque to translucent | White<br>Gray<br>Colorless |
| **CALCITE**, varieties<br>*Chalk*<br>*Marl*<br>$CaCO_3$<br>**244** | Hexagonal<br>**M**—Loose or compact, earthy | Earthy<br>Dull<br>Opaque | White<br>Grayish<br>Yellowish white |
| **TALC**, varieties<br>*Foliated*<br>*Soapstone or steatite*<br>*French chalk*<br>$H_2Mg_3Si_4O_{12}$<br>**299** | Monoclinic<br>**C**—Thin tabular, indistinct<br>**M**—Foliated, globular, fibrous, granular, compact | Pearly<br>Greasy<br>Transparent to opaque | White<br>Greenish white<br>Gray |
| **BAUXITE**<br>$Al_2O(OH)_4$<br>**235** | Never in crystals<br>**M**—Pisolitic, oolitic, rounded disseminated grains; clay-like, earthy | Dull<br>Earthy<br>Opaque | White<br>Grayish |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **1.**<br>**2.5** | White | **F**—Earthy<br>Friable | 2.1<br>2.3 | Apparently very soft, but fine particles scratch glass. Resembles chalk and kaolinite, but gritty, and not plastic when moistened. Due to impurities may have clay odor. |
| **1.**<br>**2.5** | White | **C**—Basal (scales)<br>**F**—Earthy<br>Brittle | 2.2<br>2.6 | Not gritty like tripolite. Very strong clay odor when breathed upon. Usually adheres to tongue and becomes plastic when moistened. Greasy feel. With quartz, feldspar, corundum. |
| **1.**<br>**2.5** | White | **C**—None<br>**F**—Earthy<br>Brittle | 2.7 | *Chalk*, earthy masses; *marl*, more clay-like and frequently contains organic material—leaves, twigs. In extensive deposits. |
| **1.**<br>**2.5** | White | **C**—Basal, conspicuous, when foliated<br>**F**—Uneven, splintery<br>Sectile, laminæ flexible | 2.6<br>2.8 | Greasy or soapy feel important. *Foliated talc*, easily separable, inelastic folia or plates, H = 1; *soapstone* or *steatite*, coarse to fine granular, rather impure, H = 1.5—2.5; *French chalk*, soft, compact, marks cloth distinctly. With serpentine, dolomite, chlorite, magnesite, actinolite. |
| **1.**<br>**3.** | White | **F**—Earthy<br>Brittle | 2.5 | Clay odor when breathed upon. Usually distinguished from clay by pisolitic or oolitic structure. With clay or kaolin in nodules, grains, or irregular masses in limestone or dolomite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **SODA NITER** (Chile saltpeter) $NaNO_3$ **241** | Hexagonal **C**—Similar to those of calcite, rare **M**—Granular, crusts, efflorescences | Vitreous Transparent | Colorless White Grayish |
| **GYPSUM,** varieties *Selenite* *Satin spar* *Alabaster* *Common* $CaSO_4.2H_2O$ **264** | Monoclinic **C**—Tabular, prismatic; swallow-tail twins **M**—Cleavable, coarse or fine grained, fibrous, foliated, earthy | Pearly Vitreous Silky Dull Transparent to opaque | Colorless White Gray |
| **Melanterite** (Copperas) $FeSO_4.7H_2O$ **266** | Monoclinic **C**—Rare **M**—Capillary, fibrous, stalactitic, concretionary, powder | Vitreous Dull Transparent to translucent | White Greenish white Yellowish white |
| **Sepiolite** (Meerschaum) $H_4Mg_2Si_3O_{10}$ **300** | Monoclinic ? **M**—Compact, nodular with smooth feel; earthy, clay-like | Dull Opaque | White Grayish white |
| **Epsomite** (Epsom salt) $MgSO_4.7H_2O$ **265** | Orthorhombic **C**—Prismatic, nearly square, rare **M**—Granular, fibrous, earthy, crusts | Vitreous Dull Transparent to translucent | White Colorless Gray |
| **HALITE** (Rock salt) $NaCl$ **236** | Cubic **C**—Cubes, often skeletal or hopper-shaped **M**—Compact, cleavable, granular, fibrous, stalactitic, crusts | Vitreous Transparent to translucent | Colorless White Grayish |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 1.5<br>2. | White | C—Rhombohedral<br>F—Conchoidal<br>Brittle | 2.1<br>2.3 | Cooling and saline taste. Absorbs moisture readily. In extensive deposits. With gypsum, sand, clay, guano. |
| 1.5<br>2. | White | C—Clinopinacoidal, conspicuous; pyramidal, orthopinacoidal<br>F—Conchoidal, fibrous<br>Brittle, laminæ flexible | 2.2<br>2.4 | *Selenite*, crystals and cleavage plates, usually transparent; *satin spar*, fibrous with silky luster; *alabaster*, granular. In limestones, shales. With halite, celestite, sulphur, aragonite, dolomite, ore deposits. |
| 2. | White | C—Basal<br>F—Conchoidal, earthy<br>Brittle | 1.8<br>1.9 | On exposure loses water and crumbles. Sweet, astringent taste, somewhat metallic. Oxidation product of iron sulphide minerals—marcasite, pyrite, chalcopyrite, pyrrhotite. |
| 2.<br>2.5 | White | C—None<br>F—Conchoidal, uneven<br>Brittle | 1.<br>2. | Recognized by smooth feel, adherence to tongue, low specific gravity and lack of clay odor when breathed upon. Impressed by finger nail. With serpentine, magnesite, chlorite. |
| 2.<br>2.5 | White | C—Brachypinacoidal<br>F—Conchoidal<br>Brittle | 1.7<br>1.8 | Non-hygroscopic. Bitter, salty taste. In limestone caves. With serpentine, talc, magnesite. |
| 2.<br>2.5 | White | C—Cubic, perfect, conspicuous<br>F—Conchoidal<br>Brittle | 2.1<br>2.3 | May absorb moisture and become damp. Characteristic cubical cleavage and saline taste. With slate, gypsum, anhydrite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| MICAS | | | |
| **Lepidolite**<br>$(Li,H)_2(F.OH)_2Al_2Si_3O_9$<br>**297** | Monoclinic<br>**C**—Short prismatic<br>**M**—Coarse or fine granular, scales, cleavable plates | Pearly<br>Translucent | White<br>Pinkish white<br>Lavender<br>Gray |
| **MUSCOVITE** (Isinglass)<br>$H_2KAl_3(SiO_4)_3$<br>**295** | Monoclinic<br>**C**—Tabular, pyramidal, with orthorhombic or hexagonal outline; often large and rough<br>**M**—Scales, plates; foliated and plumose aggregates. | Vitreous<br>Pearly<br>Transparent to translucent | Colorless<br>Yellowish white<br>Brownish white |
| **APATITE**, variety *Phosphate rock*<br>$Ca_5F(PO_4)_3$, chiefly<br>**273** | Hexagonal<br>**M**—Compact, fibrous, nodular, reniform, earthy | Dull<br>Opaque | White<br>Gray |
| **CRYOLITE**<br>$AlF_3.3NaF$<br>**240** | Monoclinic<br>**C**—Small, pseudocubical rare<br>**M**—Cleavable, compact, granular | Vitreous<br>Greasy<br>Pearly<br>Transparent to translucent | Snow white<br>Gray<br>Colorless |
| **BARITE** (Heavy spar)<br>$BaSO_4$<br>**256** | Orthorhombic<br>**C**—Tabular, prismatic; crested divergent groups<br>**M**—Compact, cleavable, lamellar, fibrous, reniform | Vitreous<br>Pearly<br>Transparent to translucent | Colorless<br>White<br>Gray |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **2.**<br>**3.** | White | **C**—Basal, perfect<br>**F**—Scaly granular<br>Tough | 2.8<br>2.9 | When massive often resembles granular limestone. In pegmatites, granites, gneisses. With red tourmaline (rubellite), spodumene, cassiterite. |
| **2.**<br>**3.** | White | **C**—Basal, perfect, conspicuous<br>Tough, laminæ very elastic | 2.8<br>3.1 | Structure, perfect cleavage, and elasticity important. Large crystals often show distinct partings perpendicular to cleavage, *ruled mica*. In granitic rocks, schists, limestones. With feldspar, quartz, beryl, tourmaline, garnet, spodumene. |
| **2.**<br>**3.** | White | **F**—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | More or less impure masses, frequently resembling compact limestone. Independent beds, nodules, concretions. |
| **2.5**<br>**3.** | White | **C**—Basal, prismatic, nearly at 90°; sometimes conspicuous<br>**F**—Uneven<br>Brittle | 2.9<br>3. | Frequently resembles snow ice. Often contains disseminated siderite, chalcopyrite, galena, pyrite, fluorite, columbite. |
| **2.5**<br>**3.** | White | **C**—Basal, prismatic, conspicuous<br>**F**—Uneven<br>Brittle | 4.3<br>4.7 | Characterized by rather high specific gravity and cleavages. In metalliferous veins; pockets and lenticular masses in limestones. With galena, sphalerite, fluorite, chalcopyrite; manganese and iron ores. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CALCITE**, varieties | Hexagonal | Vitreous | White |
| *Dog tooth spar* | **C**—Scalenohedral, rhombohedral, prismatic, tabular, acicular; highly modified; twins | Dull | Grayish |
| $CaCO_3$ *Nail head spar* | | Transparent to nearly opaque | Colorless |
| *Iceland spar* | | | |
| *Satin spar* | | | |
| *Limestone* | | | |
| *Coquina* | **M**—Cleavable, granular, fibrous, banded, stalactitic, oölitic, porous, compact, crusts | | |
| *Marble* | | | |
| *Calcareous tufa* | | | |
| *Travertine* | | | |
| **242** *Stalactites, etc.* | shells | | |

**Streak—Uncolored, white, or light gray**

| | | | |
|---|---|---|---|
| **ANHYDRITE** | Orthorhombic | Vitreous | White |
| | **C**—Thick tabular, prismatic, rare | Pearly | Bluish white |
| $CaSO_4$ | | Transparent to translucent | Reddish white |
| | **M**—Granular, compact, fibrous, cleavable, lamellar, reniform | | Grayish |
| **254** | | | |
| **CELESTITE** | Orthorhombic | Vitreous | Colorless |
| | **C**—Tabular, prismatic, common; pyramidal | Pearly | White |
| $SrSO_4$ | | Transparent to translucent | Gray |
| | **M**—Compact, cleavable, fibrous, granular, reniform | | |
| **255** | | | |
| **BARITE** (Heavy spar) | Orthorhombic | Vitreous | Colorless |
| | **C**—Tabular, prismatic; crested divergent groups | Pearly | White |
| $BaSO_4$ | | Transparent to translucent | Gray |
| | **M**—Compact, cleavable, lamellar, fibrous, reniform | | |
| **256** | | | |

**Hardness 1 to 3**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.** | White | C—Rhombohedral, perfect, usually conspicuous<br>F—Conchoidal<br>Brittle | 2.7 | Rhombohedral cleavage characteristic, especially on crystals. Cleavage surfaces often striated. Very strong double refraction easily observed when transparent. To distinguish varieties, see reference. |

**Hardness 3 to 6**

| | | | | |
|---|---|---|---|---|
| **3.**<br>**3.5** | White | C—Pinacoidal, 3 directions at 90°, sometimes conspicuous<br>F—Conchoidal<br>Brittle | 2.7<br>3. | Pseudocubical cleavage sometimes noted. Granular varieties resemble marble. Not as heavy as celestite or barite. With halite, gypsum. |
| **3.**<br>**3.5** | White | C—Basal, prismatic, conspicuous<br>F—Uneven<br>Brittle | 3.9<br>4. | Usually with faint bluish tinge. Heavier than calcite, anhydrite; lighter than barite. Good cleavages. In limestones, dolomites, shales. With sulphur, gypsum, aragonite, halite, galena, sphalerite. |
| **3.**<br>**3.5** | White | C—Basal, prismatic, conspicuous<br>F—Uneven<br>Brittle | 4.3<br>4.7 | Characterized by rather high specific gravity and cleavages. In metalliferous veins; pockets and lenticular masses in limestones. With galena, sphalerite, fluorite, chalcopyrite; manganese and iron ores. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **ANGELSITE** $PbSO_4$ **257** | Orthorhombic<br>**C**—Prismatic, tabular, pyramidal<br>**M**—Compact, granular, nodular | Adamantine<br>Greasy<br>Transparent to translucent | Colorless<br>White<br>Gray |
| **CERUSSITE** $PbCO_3$ **251** | Orthorhombic<br>**C**—Tabular, prismatic, pyramidal; pseudo-hexagonal; clusters and star-shaped groups<br>**M**—Interlaced bundles, granular, stalactitic, compact | Adamantine<br>Greasy<br>Silky<br>Transparent to translucent | Colorless<br>White<br>Gray |
| **STILBITE** (Zeolite) $(Ca,Na_2)Al_2Si_6O_{16}.6H_2O$ **326** | Monoclinic<br>**C**—Twinned, sheaf-like, radial, or globular aggregates | Vitreous<br>Pearly<br>Transparent to translucent | White<br>Yellowish white<br>Gray |
| **Lepidolite** (Mica) $(Li,H)_2(F,OH)_2Al_2Si_3O_9$ **297** | Monoclinic<br>**C**—Short prismatic<br>**M**—Granular, coarse or fine; scales, cleavable plates | Pearly<br>Translucent | White<br>Pinkish white<br>Lavender<br>Gray |
| **PHOSPHATE ROCK** (Apatite) $Ca_5F(PO_4)_3$, chiefly **274** | Hexagonal<br>**M**—Compact, fibrous, nodular, reniform, earthy | Dull<br>Opaque | White<br>Gray |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **3.**<br>**3.5** | White | C—Basal, prismatic<br>F—Conchoidal<br>Brittle | 6.1<br>6.4 | Luster and very high specific gravity important. Distinguished from cerussite by absence of twins. Oxidation product of lead minerals. Usually in cracks and cavities, with galena, cerussite. |
| **3.**<br>**3.5** | White | C—Indistinct<br>F—Conchoidal<br>Brittle | 6.4<br>6.6 | Twinning, structure, luster, and specific gravity characteristic. With lead minerals—galena, pyromorphite, anglesite; also malachite, limonite. |
| **3.**<br>**4.** | White | C—Pinacoidal<br>F—Uneven<br>Brittle | 2.1<br>2.2 | Radial or sheaf-like structure. In basic igneous rocks; ore deposits. With chabazite, apophyllite, datolite, calcite. |
| **3.**<br>**4.** | White | C—Basal, perfect<br>F—Scaly, granular<br>Tough | 2.8<br>2.9 | When massive often resembles granular limestone. In pegmatites, granites, gneisses. With red tourmaline (rubellite), spodumene, topaz. |
| **3.**<br>**5.** | White | F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | More or less impure masses, frequently resembling compact limestone. Independent beds, nodules, concretions. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **ANDALUSITE**<br>$Al_2SiO_5$<br>**281** | Orthorhombic<br>**C**—Prismatic, rough, nearly square, often large without terminations<br>**M**—Columnar, fibrous, granular, disseminated | Vitreous<br>Dull<br>Transparent to opaque | White<br>Pearl gray<br>Reddish gray |
| **Wavellite**<br>$(Al.OH)_3(PO_4)_2.5H_4O$<br>**276** | Orthorhombic<br>**C**—Capillary, small<br>**M**—Crusts, globular or hemispherical, with radial fibrous structure | Vitreous<br>Translucent | White<br>Gray<br>Colorless |
| **ALUNITE** (Alum stone)<br>$K_2(Al.2OH)_6(SO_4)_4$<br>**262** | Hexagonal<br>**C**—Rhombohedrons, resembling cubes; tabular, rare<br>**M**—Compact, granular, fibrous, earthy | Vitreous<br>Pearly<br>Transparent to translucent | Colorless<br>White<br>Gray |
| **DOLOMITE**<br>$CaMg(CO_3)_2$<br>**245** | Hexagonal<br>**C**—Rhombohedral with curved surfaces (*pearl spar*)<br>**M**—Coarsely crystalline, compact, granular, friable | Vitreous<br>Pearly<br>Transparent to translucent | White<br>Gray<br>Colorless |
| **ARAGONITE**<br>$CaCO_3$<br>**249** | Orthorhombic<br>**C**—Chisel- or spear-shaped; pseudohexagonal prisms; radial, columnar, acicular aggregates<br>**M**—Branching forms (*flos ferri*), stalactitic, reniform, crusts, oölitic | Vitreous<br>Greasy<br>Transparent to translucent | Colorless<br>White<br>Gray |

Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.<br>6. | White | C—Prismatic<br>F—Uneven<br>Brittle | 3.1<br>3.2 | Due to alteration, surface may be covered with scales of mica, hence, soft. *Chiastolite*, regular, internal arrangement of dark, organic matter, best seen in cross-section. In metamorphic rocks, often as rounded or knotty projections. With cyanite, sillimanite, garnet, tourmaline. |
| 3.5<br>4. | White | C—Pinacoidal, domatic<br>F—Uneven, conchoidal<br>Brittle | 2.3<br>2.4 | Secondary mineral, occurring on surfaces of rocks or minerals as crystalline crusts with pronounced radial, fibrous structure. |
| 3.5<br>4. | White | C—Basal<br>F—Splintery, conchoidal, earthy<br>Brittle | 2.6<br>2.8 | Hardness often greater due to admixture of quartz, feldspar; then tough. Deposits and veins in feldspathic rocks. With kaolin, pyrite, opal. |
| 3.5<br>4. | White<br>Gray | C—Rhombohedral, perfect (crystals)<br>F—Conchoidal<br>Brittle | 2.9 | Crystals generally curved or saddle-shaped with pearly luster. *Marble* includes some compact varieties. Independent beds; in fissures and cavities; with ore deposits. |
| 3.5<br>4. | White | C—Pinacoidal, prismatic, indistinct<br>F—Conchoidal<br>Brittle | 2.9<br>3. | Twins common, often pseudohexagonal—prism and striated base. In cracks and cavities; with ore deposits; deposition from hot springs; in shells. With gypsum, celestite, sulphur, siderite, serpentine. |

Streak—Uncolored, white, or light gray

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **STRONTIANITE**<br>$SrCO_3$<br>**250** | Orthorhombic<br>**C**—Spear-shaped, columnar, acicular, often divergent<br>**M**—Granular, compact, fibrous, botryoidal | Vitreous<br>Transparent to translucent | Colorless<br>Gray<br>White |
| **WITHERITE**<br>$BaCO_3$<br>**251** | Orthorhombic<br>**C**—Pseudohexagonal bipyramids resembling quartz<br>**M**—Radial fibrous, compact, globular, granular, lamellar | Vitreous<br>Greasy<br>Translucent to transparent | White<br>Grayish<br>Colorless |
| **Colemanite**<br>$Ca_2B_6O_{11}.5H_2O$<br>**271** | Monoclinic<br>**C**—Prismatic, highly modified<br>**M**—Granular, cleavable, compact | Vitreous<br>Dull<br>Transparent to opaque | Colorless<br>Milky white<br>Yellowish white |
| **MAGNESITE**<br>$MgCO_3$<br>**246** | Hexagonal<br>**C**—Rhombohedral, rare<br>**M**—Compact, granular, resembling unglazed porcelain on fresh fracture | Vitreous<br>Dull<br>Translucent to transparent | Snow white<br>Gray<br>Colorless |
| **FLUORITE** (Fluor spar)<br>$CaF_2$<br>**239** | Cubic<br>**C**—Cubes, alone or modified, well developed<br>**M**—Cleavable, granular, fibrous | Vitreous<br>Transparent to translucent | Colorless<br>White<br>Greenish white |

Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 3.5<br>4. | White | C—Indistinct<br>F—Uneven<br>Brittle | 3.6<br>3.8 | Similar to aragonite. Divergent columnar structure and higher specific gravity characteristic. In ore deposits; independent masses. With galena, barite, calcite. |
| 3.5<br>4. | White | C—Indistinct<br>F—Uneven<br>Brittle | 4.2<br>4.3 | Crystals, apparently hexagonal bipyramids; massive, often radial fibrous resembling strontianite, but heavier. Usually with galena. |
| 3.5<br>4.5 | White | C—Pinacoidal, perfect, conspicuous<br>F—Uneven, conchoidal<br>Brittle | 2.2<br>2.4 | Transparent crystals, resemble those of datolite, but softer; compact masses look like chalk or porcelain. With gypsum, celestite, quartz. |
| 3.5<br>5. | White | C—Rhombohedral, perfect (crystals)<br>F—Conchoidal, conspicuous<br>Tough to brittle | 2.9<br>3.1 | Conchoidal fracture generally prominent. Compact varieties are apparently very hard. Disseminated in talcose and chloritic schists, serpentine, gypsum; independent beds. |
| 4. | White | C—Octahedral, perfect, conspicuous<br>Brittle | 3.<br>3.2 | Recognized by crystal form, octahedral cleavage, and hardness. Common gangue of metallic ores, especially galena, sphalerite, cassiterite; also with calcite, barite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| ZEOLITES<br>**CHABAZITE**<br>$CaAl_2Si_6O_{16}.8H_2O$, etc.<br>**327** | Hexagonal<br>**C**—Rhombohedral, cube-like; lenticular<br>**M**—Compact | Vitreous<br>Translucent to transparent | White<br>Colorless<br>Gray |
| ZEOLITES<br>**APOPHYLLITE**<br>$H_{14}K_2Ca_8(SiO_3)_{16}.9H_2O$<br>**326** | Tetragonal<br>**C**—Prismatic, pyramidal, pseudocubical, tabular<br>**M**—Lamellar, granular, compact | Vitreous<br>Pearly<br>Transparent to nearly opaque | Colorless<br>White<br>Yellowish white |
| **Pectolite** (Pyroxene)<br>$(Ca,Na_2)_2(SiO_3)_2$<br>**307** | Monoclinic<br>**C**—Acicular, rarely terminated; tabular<br>**M**—Compact radial fibrous aggregates | Vitreous<br>Silky<br>Translucent to opaque | White<br>Grayish |
| **CYANITE** (Disthene, kyanite)<br>$Al_2SiO_5$<br>**282** | Triclinic<br>**C**—Long, bladed, without good terminations; sometimes curved and radially grouped<br>**M**—Coarsely bladed, columnar, fibrous | Vitreous<br>Translucent to transparent | White<br>Grayish<br>Colorless |
| **Scheelite**<br>$CaWO_4$<br>**259** | Tetragonal<br>**C**—Pyramidal, small; more rarely tabular<br>**M**—Drusy crusts, compact, reniform, granular, disseminated | Adamantine<br>Greasy<br>Transparent to translucent | Gray<br>White<br>Yellowish white |

Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 4.<br>5. | White | C—Rhombohedral, not conspicuous<br>F—Uneven<br>Brittle | 2.1<br>2. | Generally in cube-like crystals. Inferior cleavage distinguishes it from fluorite. In basic igneous rocks. With analcite, stilbite. |
| 4.<br>5. | White | C—Basal, perfect, conspicuous<br>F—Uneven<br>Brittle | 2.3<br>2.4 | Fish-eye opalescence often observed on basal pinacoid. Prism faces vertically striated. In fissures and cavities in basic igneous rocks. With natrolite, analcite, datolite, native copper, calcite. |
| 4.<br>5. | White<br>Grayish | C—Basal, orthopinacoidal<br>F—Uneven, fibrous<br>Brittle | 2.7<br>2.8 | Fibers usually divergent, long, and very sharp. In fissures and cavities in basic igneous and metamorphic rocks. With zeolites, datolite. |
| 4.<br>5. | White | C—Pinacoidal perfect, conspicuous<br>Brittle | 3.5<br>3.7 | Often with bluish streaks or spots irregularly distributed. Hardness varies with direction, 4–5 parallel to long direction, 6–7 at right angles thereto. In gneiss, mica schist. With staurolite, garnet, corundum. |
| 4.5 | White | C—Pyramidal, not conspicuous<br>F—Conchoidal, uneven<br>Brittle | 5.9<br>6.2 | Small, well developed octahedral-like crystals, usually on quartz; when massive high specific gravity important. With cassiterite, wolframite, fluorite, apatite, molybdenite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Wollastonite** (Pyroxene, tabular spar)<br>$CaSiO_3$<br>**306** | Monoclinic<br>**C**—Tabular, prismatic<br>**M**—Cleavable, fibrous, granular, compact | Vitreous<br>Silky<br>Transparent to translucent | White<br>Gray<br>Colorless |
| **APATITE**<br>$Ca_5F(PO_4)_3$<br>**273** | Hexagonal<br>**C**—Prismatic, thick tabular<br>**M**—Compact, fibrous, nodular, reniform | Vitreous<br>Greasy<br>Transparent to translucent | White<br>Gray<br>Colorless |
| **HEMIMORPHITE** (Calamine)<br>$H_2Zn_2SiO_5$<br>**280** | Orthorhombic<br>**C**—Thin tabular, pyramidal, hemimorphic, highly modified<br>**M**—Compact, globular, stalactitic, fibrous, granular, cellular, earthy | Vitreous<br>Dull<br>Transparent to opaque | Colorless<br>White<br>Gray |
| **SMITHSONITE**<br>$ZnCO_3$<br>**247** | Hexagonal<br>**C**—Small, usually as druses or crusts<br>**M**—Botryoidal, stalactitic, granular, cellular, fibrous, compact | Vitreous<br>Pearly<br>Dull<br>Transparent to nearly opaque | White<br>Brownish white<br>Gray<br>Colorless |
| **ANALCITE** (Zeolite)<br>$Na_2Al_2(SiO_3)_4.2H_2O$<br>**325** | Cubic<br>**C**—Tetragonal trisoctahedrons, cubes<br>**M**—Granular, compact | Vitreous<br>Transparent to nearly opaque | Colorless<br>White<br>Grayish |

Hardness 3 to 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 4.5<br>5. | White | C—Basal, orthopinacoidal<br>F—Uneven<br>Brittle | 2.8<br>2.9 | Fibers may be parallel or divergent. Typical contact mineral often in crystalline limestone. With garnet, diopside, vesuvianite, graphite. |
| 4.5<br>5. | White | C—Basal, imperfect<br>F—Conchoidal, uneven<br>Brittle | 3.1<br>3.2 | Crystals may be vertically striated and highly modified. In crystalline limestone; ore deposits, igneous rocks. With quartz, cassiterite, fluorite, wolframite. |
| 4.5<br>5. | White | C—Prismatic<br>F—Uneven, conchoidal<br>Brittle | 3.3<br>3.5 | Crystals often in sheaf-like groups or druses in cavities. When massive may be porous. In limestones. With sphalerite, galena, and especially smithsonite. |
| 5. | White<br>Gray | C—Rhombohedral, not often observed<br>F—Uneven, splintery<br>Brittle | 4.1<br>4.5 | Cellular varieties are called *dry bone*. Often mixed with sand, clay, limonite, calcite. With zinc minerals, especially sphalerite, hemimorphite. Frequently as a pseudomorph after calcite. |
| 5.<br>5.5 | White | C—None<br>F—Uneven, conchoidal<br>Brittle | 2.2<br>2.3 | Good crystals common. In fissures and cavities in basic igneous rocks. With apophyllite, chabazite, natrolite, datolite, native copper, epidote. |

**Streak** Uncolored, white, or light gray

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **Natrolite** (Zeolite)<br>$Na_2Al(AlO)(SiO_3)_3 \cdot 2H_2O$<br>**324** | Orthorhombic<br>**C**—Slender prismatic, nearly square; radial or interlacing groups<br>**M**—Fibrous, granular, compact | Vitreous<br>Silky<br>Transparent to translucent | White<br>Colorless<br>Grayish |
| **Datolite**<br>$Ca(B.OH)SiO_4$<br>**283** | Monoclinic<br>**C**—Prismatic, pyramidal, tabular, highly modified<br>**M**—Compact fibrous, granular, botryoidal | Vitreous<br>Greasy<br>Dull<br>Transparent to opaque | Colorless<br>Greenish white<br>Gray |
| **NEPHELITE** (Nepheline, elæolite)<br>$(Na,K)_8Al_8Si_9O_{34}$<br>**301** | Hexagonal<br>**C**—Short prismatic, tabular<br>**M**—Compact, disseminated grains | Greasy<br>Vitreous<br>Transparent to opaque | White<br>Bluish gray<br>Greenish gray<br>Colorless |
| **SCAPOLITE** (Wernerite)<br>$\left\{ \begin{matrix} n Na_4Al_3Si_9O_{24}Cl \\ m Ca_4Al_6Si_6O_{25} \end{matrix} \right.$<br>**322** | Tetragonal<br>**C**—Thick prismatic, coarse, often large<br>**M**—Compact, fibrous, columnar, granular | Vitreous<br>Greasy<br>Translucent | White<br>Gray<br>Greenish gray |
| **Tremolite** (Amphibole)<br>$CaMg_3(SiO_3)_4$<br>**310** | Monoclinic<br>**C**—Bladed, without terminations<br>**M**—Compact, columnar, granular | Silky<br>Vitreous<br>Transparent to opaque | White<br>Yellowish white<br>Colorless |

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 5.<br>5.5 | White | C—Prismatic<br>F—Uneven<br>Brittle | 2.2<br>2.3 | Needle-like crystals have nearly square cross-section. With chabazite, analcite, apophyllite, stilbite, datolite. |
| 5.<br>5.5 | White | C—None<br>F—Conchoidal, uneven.<br>Brittle | 2.9<br>3. | Crystals glassy, often with greenish tinge; compact masses resemble wedgewood ware or unglazed porcelain; often with reddish, brownish, or yellowish streaks and spots. In cracks and cavities in basic igneous rocks. With native copper, calcite, zeolites. |
| 5.<br>6. | White | C—Indistinct<br>F—Conchoidal, uneven<br>Brittle | 2.6 | Distinguished from orthoclase by inferior cleavage and more greasy luster. With feldspar, cancrinite, biotite, sodalite, zircon, corundum; not with quartz. |
| 5.<br>6. | White | C—Prismatic<br>F—Conchoidal<br>Brittle | 2.6<br>2.8 | Crystals may appear as though fused. Typical contact mineral. In metamorphic rocks, especially granular limestones. With pyroxenes, amphiboles, apatite, garnet, biotite. |
| 5.<br>6. | White | C—Prismatic, conspicuous—124°<br>Brittle | 2.9<br>3.1 | Silky luster and distinct cleavage (124°) important. Common contact mineral. In limestones, dolomites, schists. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **DIOPSIDE** (Pyroxene)<br>$CaMg(SiO_3)_2$<br>**305** | Monoclinic<br>**C**—Prismatic, thick columnar, prism angle 87°<br>**M**—Compact, granular, lamellar, columnar | Vitreous<br>Dull<br>Transparent to opaque | Gray<br>Greenish gray<br>Yellowish white<br>Colorless |
| **OPAL**, varieties<br>*Precious opal*<br>$SiO_2.xH_2O$ *Milk opal*<br>*Wood opal*<br>*Hyalite*<br>*Silicious sinter*<br>*Tripolite*<br>**232** | Amorphous<br>**M**—Reniform, botryoidal, porous, earthy, compact | Vitreous<br>Pearly<br>Dull<br>Transparent to opaque | Colorless<br>Gray<br>Milk white<br>Yellowish white |
| **LEUCITE**<br>$K_2Al_2Si_4O_{12}$<br>**313** | Pseudocubic<br>**C**—Tetragonal trisoctahedrons<br>**M**—Rounded disseminated grains | Vitreous<br>Greasy<br>Translucent to opaque | Gray<br>White<br>Yellowish white |

**Streak—Uncolored, white, or light gray**

FELDSPARS

| | | | |
|---|---|---|---|
| **ORTHOCLASE**, varieties<br>$KAlSi_3O_8$ *Adularia*<br>*Sanidine*<br>*Ordinary*<br>**316** | Monoclinic<br>**C**—Prismatic, thick tabular; twins; often large<br>**M**—Cleavable, granular, disseminated | Vitreous<br>Pearly<br>Translucent to transparent | White<br>Gray<br>Colorless |
| **MICROCLINE**<br>$KAlSi_3O_8$<br>**318** | Triclinic<br>**C**—Prismatic, thick tabular; twins; often large<br>**M**—Cleavable, granular disseminated | Vitreous<br>Pearly<br>Translucent to transparent | Gray<br>White<br>Yellowish white |

(Feldspars continued on next page.)

**Hardness 3 to 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **5.**<br>**6.** | White<br>Gray | C—Prismatic; conspicuous basal parting<br>F—Uneven<br>Brittle | 3.2<br>3.3 | Prismatic, pseudotetragonal crystals, with distinct basal parting. May show colorless and dark green zones. In crystalline limestones. With vesuvianite, garnet, scapolite, spinel, apatite. |
| **5.5**<br>**6.** | White | F—Conchoidal, conspicuous when compact; earthy<br>Brittle | 2.1<br>2.3 | *Precious opal*, with play of colors; *milk opal*, compact, milk white; *wood opal*, woody structure; *hyalite*, resembles drops of melted glass; *silicious sinter*, porous or botryoidal; *tripolite*, earthy and gritty. |
| **5.5**<br>**6.** | White | C—Indistinct<br>F—Conchoidal<br>Brittle | 2.5 | Well developed crystals or rounded grains, disseminated in eruptive rocks. With sanidine, augite, nephelite, olivine. |

**Hardness over 6**

| | | | | |
|---|---|---|---|---|
| **6.**<br>**6.5** | White | C—Basal, clino-pinacoidal, conspicuous, 90°; often step-like<br>F—Conchoidal, uneven<br>Brittle | 2.5<br>2.6 | Distinguished from other feldspars by rectangular cleavage and absence of twinning striations. *Adularia*, opalescent, transparent or slightly cloudy; *sanidine*, glassy, tabular or square crystals. With quartz, other feldspars, mica, hornblende, zircon. |
| **6.**<br>**6.5** | White | C—Basal, brachy-pinacoidal, conspicuous, 90° 30′<br>F—Uneven<br>Brittle | 2.5<br>2.6 | Resembles orthoclase, but with slightly inclined cleavages and may show twinning striations on basal pinacoid. Occurrence and associates same as for orthoclase. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **FELDSPARS** — Plagioclases | | | |
| **ALBITE** $NaAlSi_3O_8(Ab)$ **319** | Triclinic **C**—Tabular, twins, small **M**—Compact, curved or divergent lamellar, granular | Vitreous Pearly Transparent to translucent | White Gray Colorless |
| **LABRADORITE** $Ab_1An_1 \ldots Ab_1An_3$ **321** | Triclinic **C**—Thin tabular, often with rhombic cross-section **M**—Compact, cleavable, granular | Vitreous Pearly Translucent to nearly opaque | Gray Greenish gray White |
| **Anorthite** $CaAl_2Si_2O_8(An)$ **322** | Triclinic **C**—Prismatic, tabular complex **M**—Compact, cleavable, lamellar | Vitreous Pearly Transparent to translucent | Colorless White Gray |
| **SPODUMENE** (Pyroxene) $LiAl(SiO_3)_2$ **308** | Monoclinic **C**—Prismatic, tabular, vertically striated **M**—Cleavable, broad columnar | Vitreous Pearly Transparent to opaque | White Grayish white Greenish white |
| **Sillimanite (Fibrolite)** $Al_2SiO_5$ **282** | Orthorhombic **C**—Long, thin, needle-like **M**—Fibrous, columnar, radiating | Vitreous Silky Transparent to translucent | Gray Yellowish gray Grayish white |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>6.5 | White | C—Basal, brachypinacoidal, conspicuous, 86° 24′<br>F—Uneven<br>Brittle | 2.6 | Inclined cleavages often show fine, parallel twinning striations. *Moonstone*, opalescent. With quartz, other feldspars, mica, chlorite, beryl, rutile. |
| 6.<br>6.5 | White | C—Basal, brachypinacoidal, conspicuous, 86° 4′<br>F—Uneven<br>Brittle | 2.7 | Often with play of colors—yellow, green, blue, red. Inclined cleavages are striated. In basic igneous rocks. With pyroxenes, amphiboles. |
| 6.<br>6.5 | White | C—Basal, brachypinacoidal, conspicuous, 85° 50′<br>F—Uneven<br>Brittle | 2.7<br>2.8 | Commonly in small, glassy, highly modified crystals. In basic igneous rocks; crystalline limestones. With olivine, pyroxenes, pyrrhotite, magnetite. |
| 6.<br>7. | White | C—Prismatic; pinacoidal parting conspicuous<br>F—Uneven, splintery<br>Brittle | 3.1<br>3.2 | Commonly in broad plates due to distinct pinacoidal parting. Prism angle 93°. May have irregular brownish stains. In granitic rocks. With tourmaline, lepidolite, beryl. |
| 6.<br>7. | White | C—Macropinacoidal<br>F—Uneven<br>Brittle | 3.2<br>3.3 | Crystals often large, bent, striated, with rounded edges, without good terminations, and interlaced. In metamorphic rocks—mica schist, gneiss. With andalusite, zircon. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **CYANITE** (Disthene, kyanite) $Al_2SiO_5$ **282** | Triclinic **C**—Long, bladed, without good terminations; sometimes curved and radially grouped **M**—Coarsely bladed, columnar, fibrous | Vitreous Translucent to transparent | White Grayish Colorless |
| **ANDALUSITE** $Al_2SiO_5$ **281** | Orthorhombic **C**—Prismatic, rough, nearly square, often large, without terminations **M**—Columnar, fibrous, granular, disseminated | Vitreous Dull Translucent to opaque | White Pearl gray Reddish gray |
| **GARNET,** variety *Grossularite* $Ca_3Al_2(SiO_4)_3$ **290** | Cubic **C**—Dodecahedrons, tetragonal trisoctahedrons, alone or in combination **M**—Granular, compact, lamellar, disseminated grains | Vitreous Transparent to translucent | Colorless White Greenish white Yellowish white |
| **QUARTZ,** Phanerocrystalline varieties *Rock crystal* *Milky quartz* *Ordinary* $SiO_2$ | Hexagonal **C**—Prismatic, horizontally striated columnar **M**—Compact, granular | Vitreous Greasy Transparent to translucent | Colorless White Gray Milky |
| Cryptocrystalline varieties *Chalcedony* *Agate* *Onyx* *Hornstone* *Chert* **222** | Hexagonal **C**—Never in crystals **M**—Nodular, botryoidal, banded, clouded, concretionary, stalactitic, compact | Waxy Vitreous Translucent to opaque | White Gray |

(Quartz continued on next page.)

Hardness over 6

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| 6.<br>7. | White | C—Pinacoidal, perfect, conspicuous<br>Brittle | 3.5<br>3.7 | Often with bluish streaks or spots, irregularly distributed. Hardness varies with direction, 4–5 parallel to long direction, 6–7 at right angles thereto. In gneiss, mica schist. With staurolite, corundum, garnet. |
| 6.<br>7.5 | White | C—Prismatic<br>F—Uneven<br>Brittle | 3.1<br>3.2 | Due to alteration, surface may be coated with scales of mica, then softer. In metamorphic rocks, often as rounded or knotty projections. With cyanite, sillimanite, garnet. |
| 6.5<br>7.5 | White | C—Dodecahedral, usually indistinct<br>F—Conchoidal, uneven<br>Brittle | 3.4<br>3.7 | Typical contact mineral, in crystalline limestones and dolomites. With wollastonite, vesuvianite, diopside, scapolite. |
| 7. | White | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle | 2.6 | Characteristic conchoidal fracture, glassy luster. *Rock crystal*, colorless, or nearly so, generally crystallized; *milky quartz*, milk white and nearly opaque. |
| 7. | White | C—Indistinct<br>F—Conchoidal, conspicuous<br>Brittle to tough | 2.6 | Not as glassy as phanerocrystalline varieties. *Chalcedony*, *hornstone*, *chert*, uniform in color; *agate*, *onyx*, clouded or banded. To distinguish, see reference. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **QUARTZ** Clastic varieties *Sand* *Sandstone* *Itacolumite* *Quartzite* $SiO_2$ **222** | Hexagonal **M**—Grains, fragments, either loose or strongly consolidated | Vitreous Dull Translucent to opaque | Gray White |
| **ZIRCON** $ZrSiO_4$ **225** | Tetragonal **C**—Square prisms with bipyramids, small, well developed **M**—Irregular lumps, grains | Adamantine Vitreous Pearly Transparent to opaque | Brownish gray Lavender gray Colorless |
| **BERYL** $Be_3Al_2(SiO_3)_6$ **313** | Hexagonal **C**—Long prismatic, often vertically striated, large **M**—Columnar, granular, compact | Vitreous Transparent to translucent | White Yellowish white Greenish white Colorless |
| **TOPAZ** $Al_2(F,OH)_2SiO_4$ **283** | Orthorhombic **C**—Prismatic, vertically striated, highly modified **M**—Compact, granular, rolled fragments | Vitreous Transparent to opaque | Colorless White Grayish |
| **CORUNDUM** $Al_2O_3$ **228** | Hexagonal **C**—Prismatic, tabular, pyramidal, rhombohedral; rough or rounded barrel-shaped **M**—Compact, granular, lamellar | Vitreous Translucent to transparent | Gray Greenish gray Bluish gray |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **7.** | White | C—Indistinct<br>F—Uneven<br>Brittle to tough | 2.6 | *Sand*, loose, unconsolidated grains; *sandstone*, consolidated sand; *itacolumite*, flexible sandstone; *quartzite*, metamorphosed sandstone. |
| **7.5** | White | C—Indistinct<br>F—Uneven<br>Brittle | 4.4<br>4.8 | In acid igneous rocks—granite; syenite; alluvial deposits; with gold, spinel, corundum, garnet. *Jargon*, colorless or smoky. |
| **7.5**<br>**8.** | White | C—Indistinct<br>F—Conchoidal, uneven<br>Brittle | 2.6<br>2.8 | Crystals usually simple—prism and base. In granitic rocks, mica schists, clay slates. With quartz, feldspars, mica, chrysoberyl, garnet, topaz, tourmaline. |
| **8.** | White | C—Basal, perfect, conspicuous<br>F—Conchoidal, uneven<br>Brittle | 3.4<br>3.6 | Crystals usually developed on one end only. Massive varieties distinguished from quartz by higher specific gravity and basal cleavage. In veins and cavities in granitic rocks; alluvial deposits. With cassiterite, tourmaline, fluorite, beryl, scheelite, wolframite. |
| **9.** | White | C—None, nearly rectangular basal and rhombohedral partings conspicuous; often striated<br>F—Conchoidal<br>Brittle to tough | 3.9<br>4.1 | When massive often multicolored—blue, green, red, yellow. In limestones, granites, syenites, schists, alluvial deposits. With magnetite, nephelite, mica, spinel, chlorite. |

**Streak—Uncolored, white, or light gray**

| Name, Composition, and Reference | Crystallization Structure Crystals = C Massive = M | Luster Transparency | Color |
|---|---|---|---|
| **DIAMOND**<br><br>C<br><br><br><br>188 | Cubic<br>C—Octahedrons, hexoctahedrons, usually with curved surfaces<br>M—Rounded or irregular grains or pebbles, often with internal radial structure | Adamantine<br>Greasy<br>Transparent to translucent | Colorless<br>Gray<br>White |

**Hardness over 6**

| Hardness | Streak | Cleavage = C<br>Fracture = F<br>Tenacity | Specific Gravity | Characteristics and Associates |
|---|---|---|---|---|
| **10.** | Ash gray | **C**—Octahedral, perfect, usually conspicuous<br>**F**—Conchoidal<br>Brittle | 3.5 | May be tinged yellow, brown, red, blue. In serpentine rocks—kimberlite, peridotite, called *blue ground;* placers; with pyrope, magnetite, chromite, cassiterite, zircon, gold. |

# INDEX

Names of minerals described or referred to in the text are printed in **heavy-faced type,** synonyms and names of varieties in *italics,* and general subjects in light-faced type. When there is more than one reference, the important one is printed in heavy-faced type.


A

**Actinolite, 311,** 466, 476
  schist, 311
*Adularia,* **317,** 538
*Agate,* **223,** 331, 456, 512, 542
  *banded,* 223
  *clouded,* 223
  *moss,* 223
Agricola, G., xii
Airy's spirals, 122
**Alabandite,** 207
*Alabaster,* **264,** 520
**Albite,** 81, 86, 87, **319,** 331, 359, 540
  law, 320
*Alexandrite,* **271,** 331, 484
*Allanite,* **287,** 388, 426, 432
Allochromatic, 88
*Almandite,* **292,** 331, 392, 434, 456, 510
Aloxite, 340
**Altaite,** 214
Aluminates, 267
Aluminum, minerals, 339
  tests for, 170
  -uranium, 362
*Alum stone,* **262,** 448, 528
Alundum, 235, 340
**Alunite, 262,** 339, 357, 448, 528
*Amazonite,* **318,** 331
*Amazonstone,* **318,** 331, 478
*Amethyst,* **222,** 331, 456, 482
  *oriental,* **229,** 330, 456, 484
Ammonal, 340
Ammonium, test for, 171
Amorphous, 96
**Amphibole,** 77, **309,** 312, 339, 343, 349, 351, 388, 424, 432, 462, 466, 476, 494, 536
**Analcite,** 21, **325,** 359, 450, 534
Analyzer, 104
**Andalusite, 281,** 331, 339, 454, 520, 542
**Andesine,** 319
Andesite, 139
*Andradite,* **292,** 331, 392, 434, 456, 480, 510
Angles, constancy of, 1
**Anglesite, 257,** 350, 526
**Anhydrite,** xiii, **254,** 343, 430, 468, 524
Anisotropic, 102
Anorthic system, 78
**Anorthite, 322,** 343, 540
*Antimonite,* 204
Antimony, gray, 204
  minerals, 341
  tests for, 171
**Apatite,** 45, **273,** 343, 348, 356, 428, 430, 450, 472, 496, 500, 504, 522, 526, 534
  *chloro,* 274
  *fluor,* 274
Aplite, 139
**Apophyllite,** 61, **326,** 357, 448, 532
*Aquamarine,* **314,** 330, 482
**Aragonite,** 70, 86, 87, **249,** 343, 502, 528
  test for, 169
**Argentite,** 21, **213,** 358, 396
*Arizona ruby,* **292,** 331, 332
Arkose, 140
**Arsenic, 194,** 341, 398, 404
  minerals, 341
  tests for, 171
*Arsenical gold ore,* 204
Arsenides, 202, 203
**Arsenopyrite,** 71, **211,** 341, 349, 404
**Asbestos, 311,** 464, 494, 516
  *amphibole,* **311,** 464, 494, 516
  *chrysotile,* **298,** 464, 494, 516
  *long fibered,* **311,** 464
  *short fibered,* 298, **311,** 464
Assembly of blowpipe apparatus, 147

Asterism, 89
Asymmetric system, 78
**Augite, 307,** 388, 424, 432, 464, 478
*Auripigment*, 204
*Aventurine*, **222,** 331, 456, 512
Axes, crystallographic, 3
of symmetry, 11
optic, 102
dispersion of, 120
Axial ratio, 6
**Axinite,** 81
Axis, brachy, 65, 78
clino, 72
intermediate, 30
lateral, 30
macro, 65, 78
ortho, 72
principal, 30, 55
**Azurite, 252,** 331, 347, 462
*Azurmalachite*, 253

B

**Barite, 71, 256,** 342, 468, 470, 498, 522, 524
Barium, minerals, 342
tests for, 172
Bar theory, 237
*Barytes*, 256
Basal pinacoid, 75
Basalt, 139
**Bauxite, 235,** 339, 438, 486, 518
Baveno law, 86, 316
Bauer, M., 329
Bead tests, 163
Becke, F. J., 106
method, 105
**Beryl,** 38, **313,** 330, 339, 342, 482, 514, 544
*golden*, 313
*yellow*, 313
Beryllium, minerals, 342
tests for, 172
Biaxial crystals, 102, **116**
behavior in polarized light, 171
figures, 118, 119
**Biotite, 294,** 349, 351, 382, 428, 468
Bipyramid, ditetragonal, 57
hemi, 73
hexagonal, first order, 32
second order, 33
third order, 43
orthorhombic, 66
tetra, 78
Bipyramid, tetragonal, first order, 56
second order, 57
Birefringence, 102
**Bismuth, 195,** 342, 402, 408
flux, 147
reactions with, **153,** 157
minerals, 342
tests for, 172
**Bismuthinite,** 205
Bisphenoids, tetragonal, 62
*Black jack*, **205,** 384, 430
sand, 249
Blanc fixé, 342
*Blende*, 205
*zinc*, 205
*Bloodstone*, **223,** 331
Blowpipe, 145
apparatus, 145, 147
methods, 145
portable outfit, 150
reactions, 152
reagents, 147
Blue ground, 189
*stone*, 266
*vitriol*, **266,** 460, 468
*Bog iron ore*, **235,** 488
**Boracite,** 26
Borates, 267
Borax bead, 147
reactions with, 163
**Bornite, 216,** 347, 349, 408, 420
Boron, minerals, 343
tests for, 173
*Bort*, 188, **191,** 438
*Bortz*, 188, **191**
Boule, 337
**Bournonite, 217,** 341, 347, 350, 396
Brachy, axis, 65, 78
bipyramid, 67
dome, 68
hemi, 79
prism, 67
Brazilian law, 85, 221
Breccia, 141
Breithauptite, 208
Brilliant cutting, 190
*Brimstone*, 193
**Brochantite, 263,** 347, 460
*Bröggerite*, 262
Bromine, tests for, 173
**Bronzite, 304,** 476, 506
Brush, G. J., 145
**Bytownite,** 319

## C


Cadmium, tests for, 173
*Cairngorm stone*, **222**, 331
*Calamine*, 247, **280**, 504, 534
**Calcite**, xiii, 41, 82, 83, 84, 135, **242**, 343, 344, 428, 446, 468, 498, 518, 524
  test for, 169
Calcium, minerals, 343
  tests for, 173
*Calc spar*, 242
*Californite*, **288**, 331
**Cancrinite**, **302**, 359, 506
*Cape ruby*, **292**, 331, 332
Carbon, minerals, 345
  tests for, 174
*Carbonado*, 188, **192**, 438
Carbonates, 241
*Carbuncle*, **292**, 331
*Carnelian*, **223**, 331, 456
**Carnotite**, **277**, 362, 363, 486
**Cassiterite**, 85, **226**, 361, 392, 418, 426, 434, 444, 454, 492, 510
  test for, 169
*Cat's eye*, **222**, **271**, 331, 482, 484, 512
**Celestite**, **255**, 360, 472, 524
Center of symmetry, 12
**Cerargyrite**, **238**, 358, 492, 516
Cerium, minerals, 346
  test for, 174
**Cerussite**, **251**, 350, 500, 526
**Chabazite**, 42, **327**, 448, 532
**Chalcanthite**, **266**, 460, 468
*Chalcedony*, **223**, 331, 436, 482, 512, 542
**Chalcocite**, **214**, 347, 349, 396
**Chalcopyrite**, 64, **215**, 347, 406, 410
*Chalcotrichite*, 232
*Chalk*, **244**, 518
  *French*, **299**, 518
*Chalybite*, 248
Charcoal support, 146
  reactions on, 156
Chemical formulas, 125
  calculation of, 125
*Chert*, **224**, 542
*Chessylite*, 252
*Chiastolite*, 281
*Chile saltpeter*, **241**, 494, 520
*China clay*, **301**, 518
**Chloanthite**, 210
Chlorine, tests for, 174
**Chlorite**, **297**, 339, 351, 382, 422, 460, 466
**Chondrodite**, **286**, 348, 251, 454, 508
Chromates, 254
*Chrome iron*, 270
**Chromite**, **270**, 346, 349, 388, 426
Chromium, minerals, 346
  tests for, 175
**Chrysoberyl**, **271**, 331, 339, 342, 484, 516
**Chrysocolla**, **293**, 331, 347, 460, 466, 468
*Chrysoiite*, **289**, 480
*Chrysoprase*, **223**, 331, 482
*Chrysotile*, **298**, 464, 494
**Cinnabar**, 53, 54, **215**, 354, 412, 438
*Cinnamon stone*, **292**, 330
*Citrine*, **222**, 331
Civilization and mineralogy, ix
Class, dihexagonal bipyramidal, 3
  ditetragonal bipyramidal, 55
  ditrigonal pyramidal, 46
    scalenohedral, 38
  dyakisdodecahedral, 27
  hexagonal bipyramidal, 42
  hexoctahedral, 14
  hextetrahedral, 22
  monoclinic prismatic, 73
  orthorhombic bipyramidal, 65
  pinacoidal, 78
  tetragonal scalenohedral, 61
  trigonal trapezohedral, 50
Classes, of crystals, 13
  of symmetry, 13
**Clausthalite**, 214
Cleavage, 93
*Cleveite*, 262
Clino-axis, 72
  dome, 74
  hemi-bipyramid, 74
  pinacoid, 75
  prism, 74
*Clinochlorite*, **297**, 382, 422, 460, 466
Clinorhombic system, 72
Clinorhomboidal system, 78
*Clinozoisite*, 287
Closed tube, 146
  reactions in, 165
Cobalt, *glance*, 210
  minerals, 347
  nitrate, 148
  test for, 175
**Cobaltite**, **210**, 341, 347, 404
Coefficients, rationality of, 7
*Cog wheel ore*, **217**, 316
**Colemanite**, **271**, 343, 530
Colloids, 96

Color, of minerals, 88
change of, 89
play of, 89
Colored screens, 161
Colors, interference, 112
Columbates, 272
**Columbite, 273,** 349, 353, 355, 392, 400
Columbium, test for, 175, 179
Combination, 6
Conglomerate, 141
Congruent, 23
Cooperite, 364
**Copper,** 21, 97, 135, **196,** 347, 408, 412
*blue carbonate of*, 252
*green carbonate of*, 252
minerals, 347
*nickel*, 208
*plush*, 232
*shot*, 197
tests for, 175
*Copperas*, **266,** 466, 520
*Copper ore, gray*, 218
*horse flesh*, 216
*purple*, 216
*ruby*, 232
*yellow*, 215
*Coquina*, **244,** 524
**Corundum,** 42, **228,** 330, 339, 394, 402, 424, 458, 484, 516, 544
**Covellite,** 215
Critical angle, 101
**Crocoite, 258,** 346, 350, 440
Cross, axial, 3
**Cryolite, 240,** 339, 348, 359, 522
Cryptocrystalline, 96
Crystal, aggregate, 96
form, 5
systems, 4
Crystalline aggregate, 96
Crystallization, elements of, 7
Crystallography, xiv, 1
subdivisions of, 1
Crystalloids, 96
Crystals, xiii
classes of, 13
Cube, 16
pyramid, 18
Cubic system, **14,** 372
**Cuprite, 232,** 347, 416, 442
Cupro-titanium, 362
**Cyanite, 282,** 331, 339, 472, 480, 532, 542
*Cymophane*, **271,** 331

D

Dana, J. D., 186
**Datolite, 283,** 331, 343, 450, 474, 536
Dauphine law, 85, 221
Deltoid, 23
*Desmine*, 326
*Demantoid*, **292,** 331
*Diallage*, 306
**Diamond, 188,** 330, 345, 438, 544
cutting of, 190
*matura*, 226
Diamonds, famous, 191
Diaphaneity, 95
*Diatomaceous earth*, 234
Dichroic, 122
Didodecahedron, 27
Dihexagonal, bipyramid, 34
bipyramidal class, 31
prism, 37
Dimorphism, 130
**Diopside, 305,** 331, 476, 538
Diorite, 139
Diploid, 27
Dispersion, 100
of diamond, 100
of glass, 101
of optic axes, 120
*Disthene*, **282,** 472, 480, 532, 542
Distortion, 2
Ditetragonal, bipyramid, 57
prism, 59
Ditrigonal, prisms, 47, 52
pyramidal class, 46
pyramids, 46
scalenohedral class, 38
Dodecahedron, pentagonal, 27
rhombic, 16
trigonal, 24
*Dogtooth spar*, **243,** 498, 524
Dolerite, 139
**Dolomite,** 141, **245,** 343, 344, 351, 500, 528
test for, 169
Dome, 68
brachy, 68
clino, 74
hemi-brachy, 79
-macro, 79
-ortho, 75
macro, 69
*Dry bone*, 247
Dyakisdodecahedron, 27

Dyakisdodecahedral class, 26
*Dysluite*, **268**, 394, 436

E

*Earth, diatomaceous*, 234
*infusorial*, 234
*Elaeolite*, **301**, 474
Elements, 187
of crystallization, **7**
of symmetry, 10
*Emerald*, **314**, 330, 482
*oriental*, **229**, 330, 484
*Emery*, **228**, 394, 402, 428
**Enargite, 219**, 341, 347, 398
*Endlichite*, 275
**Enstatite**, 304
**Epidote, 286**, 331, 339, 343, 349, 434, 480, 510
rock, 287
schist, 287
**Epsomite, 265**, 520
Etch figures, 24
Exolon, 340

F

Faces, regular position of, 12
**Fayalite**, 289
Feel, 95
**Feldspar, 315**, 316, 331, 339, 432, 452, 478, 508, 538
*glassy*, 317
*lime*, 322
*lime-soda*, 321
*plagioclase*, **319**, 540
*potash*, 316
*soda*, 319
**Ferberite, 261**, 349, 362, 386, 398, 416, 424, 490
Ferrites, 267
Ferromanganese, 353
Ferro-titanium, 362
Ferro-uranium, 362
*Fibrolite*, **282**, 508, 540
Flame, colorations, 160
oxidizing, 150
reducing, 150
structure of, 150
*Flint*, **224**, 436, 512
*Flossi ferri*, 240
Fluorine, minerals, 348
test for, 176
**Fluorite**, 21, **84**, **93**, 135, **239**, 343, 348, 448, 472, 504, 530
*Fluorspar*, **239**, 448, 472, 504, 530
*Fool's gold*, 208
Form, closed, 5
crystal, 5
fundamental, 5
modified, 5
negative, 24
open, 5
positive, 24
Forms, congruent, 23
enantiomorphous, 51
relationship of, 20, 38, 60
**Forsterite**, 289
*Fowlerite*, 309
Fracture, 94
**Franklinite**, 21, **270**, 349, 353, 363, 390, 400
*Freibergite*, 218
*Fuchsite*, 296
Fusibility, scale of, 151

G

Gabbro, 139
*Gahnite*, **268**, 394, 436, 484, 514
**Galena**, 20, 21, **212**, 350, 396, 404
*Galenite*, **212**, 396, 404
Gangue, 136
**Garnet**, 21, **290**, 330, 339, 343, 349, 392, 434, 456, 480, 510, 542
**Garnerite, 300**, 351, 354, 460, 466
Gels, 96
Gems, 329
cutting, 333
methods of identification, 332
synthetic, 337
weight of, 333
Geode, 136
German silver, 355
**Gersdorffite**, 210
*Geyserite*, 234
**Glaucodote**, 212
Glossary, 366
Glucinum, test for, 172
Gneiss, 141
**Gold, 200**, 348, 406, 408
free milling, 201
minerals, 348
*ore, arsenical*, 204
placer, 200
tests for, 176
Goldschmidt, V., 11

Granite, xii, **138**
**Graphite, 192,** 345, 394, 422
**Greenockite,** 208
Greisen, 227
*Grossularite,* **292,** 330, 456, 482, 510, 542
Groth, von, P. H., 128
*Guano,* 274
**Gypsum,** 77, 86, **264,** 331, 343, 344, 444, 494, 520

H

**Halite,** 21, 24, 93, **236,** 444, 496, 520
Haloids, 236
Hardness, 90
**Hauerite,** 210
**Hausmannite, 253,** 353, 386
Hauy, R., 8
*Heliotrope,* **223,** 331, 456, 482
**Hematite,** 41, **230,** 331, 349, 382, 390, 412, 414, 438
*argillaceous,* **230,** 390, 414, 440
*black,* 253
*brown,* 235
*compact,* **230,** 390, 414, 440
*fossiliferous,* **231,** 438
*oolitic,* **231,** 438
*specular,* **230,** 382, 390
Hemi-bipyramid, 73
clino, 74
ortho, 74
Hemi-dome, brachy, 79
macro, 79
ortho, 79
**Hemimorphite, 280,** 363, 504, 534
Hemiprism, 79
Hemiprismatic system, 72
*Hercynite,* **268,** 394, 428
**Hessite,** 214
*Hessonite,* **292,** 330
Hexagonal, bipyramid, first order, 32
second order, 33
third order, 43
bipyramidal class, 42
prism, first order, 36
second order, 36, 49
third order, 43
pyramid, second order, 48
system, **30,** 373
*Hexagonite,* 310
Hexahedron, 16
Hexoctahedral class, 14
Hexoctahedron, 18
Hextetrahedral class, 22
Hextetrahedron, 24
*Hiddenite,* **308,** 331
**Hornblende, 312,** 388, 424, 432, 462, 476
*Horn silver,* **238,** 492, 516
*Hornstone,* 542
**Huebnerite, 260,** 353, 362, 386, 416, 424, 430, 442, 450, 490, 504
Human activity, divisions of, ix
*Hyacinth,* **225,** 331
*Hyalite,* **233,** 538
Hydrobromic acid, 148
reactions with, 155
Hydrogen, test for, 176
Hydroxides, 219, 232
*Hypersthene,* **304,** 331

I

Ice, 219
*stone,* 240
*Iceland spar,* **243,** 524
Icositetrahedron, 17
Idiochromatic, 88
**Ilmenite, 303,** 349, 361, 388, 400
Indices, Miller's, 10
*Infusorial earth,* 234
Invar, 355
Iodine, tests for, 176
*Idocrase,* 288
Iridescence, 89
Iron, minerals, 349
*spathic,* 248
tests for, 177
*Iron ore, bog,* **236,** 412, 414, 488
*chrome,* 270
*fossiliferous,* **230,** 412
*magnetic,* 268
*oolitic,* **230,** 412
*red,* 230
*specular,* 230
*titanic,* 303
*yellow,* **235,** 406
*Iron stone, brown clay,* **235,** 412, 414, 486
*Isinglass,* **295,** 496, 522
Isodimorphism, 130
Isometric system, 14
Isomorphism, 128
Isotropic substance, 102
behavior of in polarized light, 110
*Itacolumite,* **224,** 544

J

*Jacinth*, **225**, 331
*Jade*, **311**, 331
**Jadeite**, **311**, 331
**Jamesonite**, 218
*Jargon*, **225**, 331
*Jasper*, **223**, 456, 512
Jolly balance, 91

K

*Kaolin*, **301**, 492, 518
**Kaolinite**, **301**, 339, 492, 518
Karlsbad law, 86, 316
Keene's cement, 344
Kunz, G. F., 332
*Kunzite*, 308
*Kyanite*, **282**, 472, 480, 534, 542

L

Labradorescence, 321
**Labradorite**, **321**, 331, 432, 478, 540
La Croix, A., 187
Lamprophyre, 139
*Land plaster*, 265
*Lapis lazuli*, **303**, 331, 462, 474
Laterite, 235
**Lautarite**, 241
**Lazurite**, **303**, 331, 359, 360, 462, 474
Lead, *black*, **192**, 394, 422
  *glance*, 212
  minerals, 350
  *ore, white*, 251
  tests for, 177
Lemberg's test, 169
**Lepidolite**, **297**, 348, 351, 444, 446, 522, 526
*Lepidomelane*, 294
**Leucite**, **313**, 339, 357, 538
Leucitohedron, 17
Light, observations in, 104
  polarized, 107
  reflection of, 99
  refraction of, 99
  total reflection of, 101
*Limestone*, **141**, **243**, 428, 498
  *oolitic*, 98
**Limonite**, **235**, 349, 386, 406, 412, 414, 486, 488
  *compact*, **235**, 414
  *ochreous*, 236
Liquids, immersion, 106, 107
*Lithium*, minerals, 351
  tests for, 177
**Lionite**, 340
**Lithophone**, 342
*Lodestone*, **268**, 269
**Löllingite**, 212
Luster, 88

M

Macro-axis, 65, 78
  bipyramid, 67
  dome, 69
    hemi, 79
  prism, 67
Magnaleum, 352
Magnesia alba, 352
**Magnesite**, **246**, 351, 530
Magnesium, minerals, 351
  tests for, 178
Magnetism, 93
**Magnetite**, 21, **268**, 349, 402
**Malachite**, **252**, 331, 347, 462
  *matrix*, 252
Mannebach law, 86, 316
Manganese, *black oxide*, 227
  minerals, 353
  tests for, 178
**Manganite**, 97, **234**, 353, 384
Manganites, 253
*Marble*, xii, **142**, **244**, 428, 498, 524
**Marcasite**, **211**, 349, 406, 410
**Marialite**, 322
*Marl*, **244**, 518
*Martite*, **230**, 390
Materials, source of, ix
*Matura diamond*, 226
*Meerschaum*, **300**, 520
Meigen's test, **169**, 243, 250
**Meionite**, 323
*Melanite*, 292
**Melanterite**, **266**, 349, 466, 520
*Menaccanite*, **303**, 404
Mercury, minerals, 354
  tests for, 178
Merwin color screen, 146
  observations with, 161
**Miargyrite**, 218
**Mica**, **293**, 339, 357
  "*A*", 295
  *amber*, 294
  *black*, **294**, 382, 428

**Mica,** *bronze,* **294,** 446
*lithium,* **297,** 444, 446, 522
*magnesium,* 294
*-iron,* 294
*potash,* 295
*ribbon,* 295
*ruled,* 295
*wedge,* 295
*white,* 295
Micanite, 296
Michel-Levy, A., 138
**Microcline, 318,** 331, 357, 478, 538
Microcosmic salt bead, 147
reactions with, 163
Microscope, centering of, 104
polarizing, 103
Miller, W. H., 10
indices, 10
**Millerite,** 208
Mineral, definition of, xiii
resources, 10
Mineralogy, and civilization, xi
chemical, 14
descriptive, xiv, **186**
determinative, xiv
divisions of, xiv
history of, xii
physical, xiv
relation to other sciences, xi
Minerals, xii
accessory, **137**
classification of, 186, 339
decomposition of, 143
determination of, 379
essential, 137
formation of, 131
names of, 126
occurrence, 134
*Mispickel,* 211
Molybdates, 254
**Molybdenite, 205,** 354, 394, 402
Molybdenum, minerals, 354
tests for, 179
**Monazite, 272,** 346, 356, 452, 506
Monel, 355
Monoclinic system, **72,** 377
Monoclinohedral system, 72
Monosymmetric system, 72
*Moonstone,* **317,** 320, 331
*Morganite,* **314,** 330
**Muscovite,** 89, **295,** 496, 522

N

*Nail-head spar,* **243,** 498, 524
**Natrolite, 324,** 359, 506, 536
*Nepheline,* **301,** 474, 536
**Nephelite, 301,** 339, 357, 359, 474, 536
*Nephrite,* **311,** 331
**Niccolite, 208,** 341, 354, 410, 420
Nichrome, 355
Nickel, minerals, 354
tests for, 179
Nicol prism, 109
Niobium, minerals, 355
test for, 179
Nitrates, 240
Nitrogen, minerals, 355
tests for, 180
*Nivenite,* 262

O

Oblique system, 72
*Ocher, brown,* **235,** 412, 486
*red,* **230,** 412, 438
*yellow,* **235,** 406, 486
Octahedron, 16
Odor, 95
*Oligonite,* 249
**Olivine, 289,** 331, 349, 351, 480
*Onyx,* **223,** 331, 436, 542
*marble,* 245
**Opal, 232,** 331, 358, 452, 478, 492, 508, 518, 538
*fire,* **233,** 331, 452
*jasper,* **233,** 452, 508
*milk,* **233,** 538
*precious,* **233,** 331, 508, 538
*wood,* **233,** 508, 538
*resin,* 233
Opalescence, 89
Open tube, 146
reactions in, 164
*Ore, kidney,* 231
**Orpiment, 204,** 341, 486
**Orthite, 287,** 343, 346, 349, 388, 426, 432
Ortho, axis, 72
hemi-bipyramid, 74
pinacoid, 75
prism, 74
**Orthoclase,** 77, 86, 134, **316,** 331, 357, 452, 508, 538

Orthorhombic, bipyramid, 66
bipyramidal class, 65
system, **65,** 376
Oxides, 219
Oxygen, tests for, 108

P

Parameters, 4
Parametral ratio, 4
Paramorphs, 143
Parting, 94
Paste, 188
**Patronite, 363**
**Pearceite,** 218
*Pearl spar*, 245
**Pectolite, 307,** 359, 532
Pegmatite, 139
*Pencil rock*, 264
Penfield, S. L., 125
Pentagonal dodecahedron, 27
regular, 27
**Pentlandite,** 207
Pericline law, 87, 320
*Peridot*, **289,** 331, 480
*Perthite*, 321
**Petzite,** 214
**Phlogopite, 294,** 351, 446, 496
*Phosphate rock*, **273,** 428, 430, 496, 500, 522, 526
Phosphates, 272
Phosphorus, minerals, 356
tests for, 180
*Picotite*, **268,** 394, 408, 492
Pinacoid, 59
basal, 37, 69, 75, 79
brachy, 69, 79
clino, 75
macro, 69, 79
ortho, 75
Pinacoidal class, 78
*Pitchblende*, **262,** 384, 398, 414, 420, 422
Placers, 136
**Plagioclase, 319,** 343, 359, 540
Planes of symmetry, 10
Plaster of Paris, 265
Plaster tablet, 146
reactions on, 152
**Platinum, 195,** 356, 402
minerals, 356
tests for, 180
Pleochroism, 122
*Pleonaste*, **268,** 394, 436, 484, 514
*Plumbago*, **192,** 394, 422
Pneumatolysis, 133
Polar, 23
Polarized light, 107
by absorption, 107
by reflection, 108
by refraction, 108
circular, 120
convergent, 110
observations in, 123
parallel, 110
Polarizer, 104
**Polybasite,** 218
Polymorphous, 130
Potash salts, 238
Potassium, minerals, 357
test for, 181
Precious stones, 239
cutting of, 333
methods of identification, 332
synthetic, 337
weight of, 333
Prism, brachy, 67
clino, 74
ditetragonal, 59
hemi, 79
hexagonal, first order, 36
second order, 36
third order, 43
macro, 67
ortho, 74
tetragonal, first order, 59
second order, 59
dihexagonal, 37
ditrigonal, 47, 52
trigonal, 47
Prismatic system, 65
*Prochlorite*, **297,** 382, 422, 460, 466
**Proustite, 217,** 341, 358, 412, 440
Pseudomorphs, 143, 144
Pseudosymmetry, 57
**Psilomelane, 253,** 353, 388, 400, 426
Pycnometer, 92
Pyramidal system, 55
Pyramid tetrahedron, 24
**Pyrargyrite, 217,** 341, 358, 382, 412, 440
**Pyrolusite, 227,** 353, 396
**Pyrite,** 25, 29, 84, **208,** 331, 349, 408, 410
*Pyrites, copper*, 215
*iron*, **208,** 408, 410
*magnetic*, 207
*spear*, 211
*white iron*, **211,** 406, 410

Pyritohedron, 27
**Pyromorphite, 275,** 350, 356, 462, 472, 490, 502
*Pyrope*, **292,** 331, 351, 456
**Pyroxene, 77, 304,** 307, 331, 343, 349, 351, 388, 424, 432, 452, 464, 476, 478, 506, 508, 532, 538, 540
**Pyrrhotite, 207,** 349, 410, 420

Q

Quadratic system, 55
**Quartz,** xiv, 53, 54, 82, 83, 85, 134, 136, **220,** 331, 358, 436, 456, 482, 512, 542, 544
*cap*, 221
*clastic*, 222, **224**
*cryptocrystalline*, 222, **223**
*crystalline*, 222
*ferruginous*, **222,** 456, 512
*granular*, 224
*milky*, **222,** 542
*rose*, **222,** 331, 456
*rutilated*, **222,** 331
*scepter*, 221
*smoky*, **222,** 331, 436, 512
*Quartzite*, **142, 224,** 456, 512, 544

R

**Rammelsbergite,** 212
Ratio, axial, 6
parametral, 4
Rationality of coefficients, **7**
**Realgar, 203,** 341, 438
Refraction, double, 101
character of, 116
strength of, 112, 116
index of, **100,** 105, 111
single, 99
Refractometer, Smith's, 332
Regular system, 14
Relationship of forms, 20, 38, 60
Relief, 106
**Rhodochrosite, 248,** 353, 448
*Rhodolite*, **292,** 331
**Rhodonite, 309,** 331, 353, 452, 508
Rhombic, dodecahedron, 16
system, 65
Rhombohedron, **39,** 50
Rhyolite, 139
*Rock crystal*, **222,** 331, 542
Rocks, xii, **137**
dike, 139
extrusive, 138
igneous, 137
intrusive, 138
metamorphic, 141
plutonic, 138
sedimentary, 140
volcanic, 138
*Roscoelite*, **296,** 363
*Rubellite*, **284,** 331, 332, 458
*Rubicelle*, **268,** 330, 458
*Ruby*, **228,** 330, 456
*Arizona*, **292,** 331, 332
*cape*, **292,** 331, 332
**Rutile,** 61, **224,** 361, 392, 418, 426, 434, 444, 454, 490, 510

S

**Safflorite,** 212
*Salt, common*, 236
*epsom*, **265,** 520
*rock*, **236,** 444, 496, 520
Salt of phosphorus, 147
reactions with, 163
*Sand*, **224,** 456, 512, 544
*black*, 269
*Sandstone*, xii, 140, **224,** 456, 512, 544
*Sanidine*, **317,** 538
*Sapphire*, **228,** 330, 484
*golden*, 229
*white*, 229
*yellow*, 229
*Sard*, **223,** 331, 456
*Satin spar*, **264,** 331, 494, 520
Scalenohedron, 40
tetragonal, 62
**Scapolite, 332,** 339, 343, 359, 452, 476, 536
**Scheelite, 259,** 343, 362, 504, 532
Schists, 142
*Schwatzite*, 218
*Selenite*, **264,** 494, 520
Selenium, test for, 181
**Sepiolite, 300,** 351, 520
*Sericite*, 296
**Serpentine,** 135, **297,** 331, 351, 430, 470, 500
Shale, 140
**Siderite, 248,** 349, 384, 414, 422, 488, 502
Silicates, 277

Silicon, minerals, 358
tests for, 181
Sillimanite, **282,** 339, 508, 540
Silver, 98, **199,** 358, 382, 402
*glance*, **213,** 396
*horn*, **238,** 492, 516
minerals, 358
tests for, 181
*Silver ore, dark ruby*, 217
*light ruby*, 217
*Sinter, calcareous*, 244
*silicious*, **234,** 508, 538
Slate, 142
Smaltite, 135, **210,** 341, 347, 404
Smith refractometer, 332
Smithsonite, **247,** 363, 474, 506, 534
Snow, 219
*Soapstone*, **299,** 464, 494, 518
Sodalite, **303,** 339, 359, 474
Soda niter, **241,** 355, 359, 494, 520
Sodium, carbonate, 147
reactions with, 158
minerals, 359
tests for, 181
Sorel cement, 351
*Spar, calc*, 242
*dog-tooth*, **243,** 498, 524
*heavy*, **256,** 468, 470, 498, 522, 524
*Iceland*, **243,** 524
*Labrador*, **323,** 331
*nail-head*, **243,** 498, 524
*pearl*, 245
*satin*, **264,** 331, 494, 520, 524
*tabular*, **306,** 534
*Spathic iron*, 248
*Spear pyrites*, 211
Specific gravity, 90
Spectroscope, 160
*Specular iron ore*, **230,** 382, 390
Spelter, 207
*Sperrylite*, 210
*Spessartite*, **292,** 331, 353, 456, 510
Sphalerite, 25, 26, 135, **205,** 363, 384, 414, 422, 430, 442, 448, 488, 502
*Sphene*, **323,** 331, 384, 450, 474, 506
Spiegeleisen, 353
Spinel, 21, **267,** 330, 339, 349, 351, 394, 426, 436, 456, 484, 492, 514
*Balas*, **268,** 458
*blue*, **267,** 330, 484
law, 84
*ruby*, **268,** 330, 458
Spodumene, **308,** 331, 339, 351, 540
*Stalactite*, **245,** 428, 498, 524
*Stalagmite*, 245
Staurolite, 85, **279,** 331, 339, 349, 436, 514
*Steatite*, **299,** 464, 494, 518
Stellite, 347
Steno, N., 2
Stephanite, 218
Stibnite, **204,** 341, 396, 404
Stilbite, **326,** 359, 446, 500, 526
Stones, precious, 329
semi-precious, 330
Strass, 188
Streak, 89
plate, 89
Stromeyerite, 214
Strontianite, **250,** 360, 502, 530
Strontium, minerals, 360
tests for, 182
Structure of minerals, 96
Sulphates, 254
Sulphides, 202, 203
Sulpho-minerals, 202, 215
Sulphur, 70, **193,** 360, 494, 496
minerals, 360
tests for, 182
Syenite, xii, **139**
Sylvite, 24
Symmetry, axes of, 11
center of, 12
classes of, 13
classification of, 372
elements of, 10
planes, 10
Synthetic gems, 337
System, anorthic, 78
asymmetric, 78
clinorhombic, 72
clinorhomboidal, 78
crystal, 4
cubic, **14,** 372
hemiprismatic, 72
hexagonal, **30,** 373
isometric, 14
monoclinic, **72,** 377
monoclinohedral, 72
monosymmetric, 72
oblique, 72
orthorhombic, **65,** 376
pyramidal, 55
prismatic, 65
quadratic, 55
regular, 14
rhombic, 65

System, tesseral, 14
tessular, 14
tetragonal, **55,** 375
triclinic, **78,** 378
trimetric, 65

T

**Talc, 299,** 351, 464, 494, 518
**Tantalite, 273,** 392, 400
Tarnish, 89
Taste, 95
Tellurium, tests for, 182
Tenacity, 94
*Tennantite,* 218
Tesseral system, 14
Tetra-bipyramid, 78
Tetragonal, bipyramid, first order, 56
second order, 57
bisphenoid, 62
prism, first order, 59
second order, 59
scalenohedral class, 61
scalenohedron, 62
system, **55,** 375
trisoctahedron, 17
tristetrahedron, 23
**Tetrahedrite,** 26, **218,** 341, 347, 349, 354, 358, 363, 384, 398
Tetrahedron, 22
Tetrahexahedron, 18
Thermite, 340
*Tiger's eye,* **223,** 331
Tin, minerals, 361
*stone,* 226
*stream,* **226,** 418
tests for, 183
*wood,* **226,** 418
Titanates, 277
**Titanite, 323,** 331, 343, 361, 384, 432, 450, 474, 506
Titanium, minerals, 361
tests for, 183
**Topaz,** 71, **283,** 330, 339, 348, 514, 544
*false,* **222,** 331, 512
*oriental,* **229,** 330, 516
*precious,* 283
*Spanish,* **222,** 331, 512
*Topazolite,* **292,** 331
Touch, 95
**Tourmaline,** 50, **284,** 331, 339, 343, 351, 392, 436, 458, 482, 512
*sun,* 284
Trachyte, 139
Transparency, 95
Trapezohedron, trigonal, **51**
*Travertine,* **244,** 428, 498, 524
**Tremolite, 310,** 536
Triboluminescence, 206
Trichroic, 123
Triclinic system, **78,** 378
Trigonal, bipyramid, second order, 50
prism, first order, 46
second order, 52
pyramid, first order, 46
trapezohedral class, 50
trapezohedron, 51
trisoctahedron, 17
tristetrahedron, 23
Trimetric system, 65
Trimorphous, 130
*Tripolite,* **234,** 492, 508, 518, 538
Trisoctahedron, tetragonal, 17
trigonal, 17
Tristetrahedron, tetragonal, 23
trigonal, 23
**Troilite,** 207
*Troostite,* **289,** 508
*Tufa, calcareous,* **244,** 428, 498, 524
Tungstates, 254
Tungsten, minerals, 362
tests for, 183
**Turquois, 276,** 331, 339, 356, 464, 478
*Turkey fat,* 247
Twin crystals, 122

U

**Ullmannite,** 210
*Ultramarine, native,* 303
Uniaxial figure, 115
substance, 102
behavior of, 110, 113
*Uralite,* **307,** 312
Uralization, 312
Uranates, 254
**Uraninite, 262,** 362, 384, 398, 414, 420, 422
Uranium, minerals, 362
tests for, 184
*Uvarovite,* **292,** 331, 480

V

Vanadates, 272
**Vanadinite, 275,** 350, 363, 440, 446, 488, 489

Vanadium, minerals, 363
tests for, 184
Veins, 135
*Verd-antique*, 298
Vermilion, natural, 215
**Vesuvianite**, 61, **288**, 331, 339, 343, 348, 480, 510
von Groth, P. H., 128

W

Water, 219
**Wavellite**, **276**, 339, 356, 472, 500, 528
Weisbach, A., 90
*Wernerite*, **322**, 452, 476, 536
*White lead ore*, 251
**Willemite**, **289**, 363, 478, 508
**Witherite**, **251**, 342, 530
Wolfachite, 212
**Wolframite**, **261**, 349, 353, 362, 386, 389, 416, 420, 424, 442, 490
**Wollastonite**, **306**, 534
*Wood, opal*, **233**, 508
*tin*, **226**, 418
Wright, F. E., 104
**Wulfenite**, **259**, 350, 354, 440, 446, 488, 498
Wurtzite, 208

Y

Yellow ammonium sulphide, 149
reactions with, 153

Z

*Zeolite, needle*, 324
*Zeolites*, **324**, 339, 343, 448, 450. 500, 506, 526, 532, 534, 536
*Zinc, blende*, 205
minerals, 363
*ore, red*, 228
tests for, 184
**Zincite**, **228**, 363, 416, 442, 490
**Zircon**, 61, **225**, 331, 364, 458, 514, 544
Zirconium, minerals, 364
tests for, 185
Zoisite, 287
Zwitter, 227

14 DAY USE
RETURN TO DESK FROM WHICH BORROWED
EARTH SCIENCES LIBRARY
This book is due on the last date stamped below, or
on the date to which renewed.
Renewed books are subject to immediate recall.

LD 21–40*m*-5,'65
(F4308s10)476

General Library
University of California
Berkeley

JUN2 1955 LU